

TIGER: AN UNSUPERVISED MACHINE LEARNING
TACTICAL INFERENCE GENERATOR

by

David Ezra Sidran

An Abstract

Of a thesis submitted in partial fulfillment
of the requirements for the Doctor of
Philosophy degree in Computer Science in the Graduate College of
The University of Iowa

July 2009

Thesis Supervisor: Associate Professor Alberto Maria Segre

ABSTRACT

We present here TIGER, a Tactical Inference Generator computer program that was designed as a test-bed program for our research, and the results of a series of surveys of Subject Matter Experts (SMEs) testing the following hypotheses:

Hypothesis 1: There is agreement among military experts that tactical situations exhibit certain features (or attributes) and that these features can be used by SMEs to group tactical situations by similarity.

Hypothesis 2: The best match (by TIGER of a new scenario to a scenario from its historical database) predicts what the experts would choose.

We have conducted three surveys of SMEs and have concluded that there is, indeed, a statistically significant confirmation of Hypothesis 1, that there is agreement among military SMEs that tactical situations exhibit certain features (or attributes) and, that these features can be used to group, or identify, similar tactical situations. The statistical confidence level for this confirmation of Hypothesis 1 is greater than twice the prior probability.

In order to test Hypothesis 2 we constructed, after SME survey analysis, a series of algorithms, which we present here, for the analysis of SME identified tactical features (or attributes) including: *interior lines, restricted avenues of approach, restricted avenues of attack, slope of attack, weighted force relationships* and *anchored or unanchored flanks*. Furthermore, the construction, and implementation, of these algorithms, required the design and implementation

of certain ‘building block’ algorithms including: *range of influence*, *optimal FindPath*, *ComputeGroupsByThreshold* and *ComputeGroupsByNumber*.

We further present an overview of TIGER, itself, and the built-in utilities necessary for creating three-dimensional tactical situations, complete with terrain, elevation and unit types as well as our implementation of Gennari, Fisher and Langley’s CLASSIT classification system.

Lastly, we present TIGER’s classification of twenty historical tactical situations and five hypothetical tactical situations and the SME survey results of TIGER’s classification that resulted in TIGER correctly predicting what the SMEs would choose in four out of five tests (using a one sided Wald test resulted in $p = 0.0001$ which is statistically significant).

Abstract Approved


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6/15/2009
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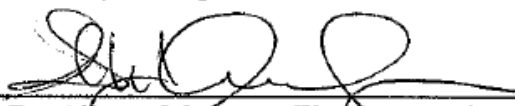
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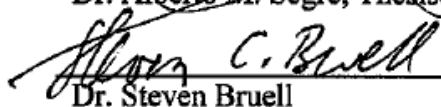
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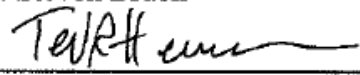
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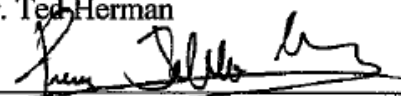
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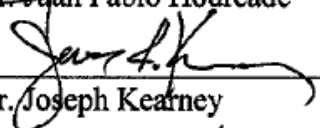
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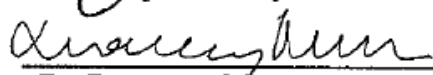

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CHAPTER I: INTRODUCTION

Our research in the field of Computational Military Reasoning, or Computational Military Tactical Planning (Kewley and Embrechts), has demonstrated that the use of an unsupervised machine learning system, such as Gennari, Langley and Fisher's CLASSIT (Gennari and Langley) can perform an accurate analysis of tactical positions validated by a series of surveys of military Subject Matter Experts (SMEs). The CLASSIT system relies on 'real-valued' attributes to describe 'instances', or tactical situations in our use, for classification. We have created a series of algorithms that return numeric values for specific attributes, or features, of tactical situations. Throughout the process of feature identification and algorithm creation, we have placed the SMEs within the development-validation loop. We agree with Cheeseman and Stutz that, "a strong interaction between the discovery program and the expert will be the common pattern in Knowledge Discovery in Databases (KDD) for the foreseeable future, because each have complementary strengths." (Cheeseman and Stutz)

Lastly, we have created TIGER (an acronym for Tactical Inference GenERator) that is a test bed program for our research. It is written in C++ and runs on any Windows™ XP or Vista™ computer. It is a fully functional program, with a graphical user interface, that supports placing military units in a three-dimensional environment, applying various experimental algorithms and outputs results via HTML, graphics and explorable data structures.

Overview of Research

Our research is based on the following hypotheses:

Hypothesis 1: There is agreement among military experts that tactical situations exhibit certain features (or attributes) and that these features can be used by SMEs to group tactical situations by similarity.

Hypothesis 2: The best match (by TIGER of a new scenario to a scenario from its historical database) predicts what the experts would choose.

We began our research by conducting a survey of military SMEs to determine the validity of our first hypothesis (see Appendix A: Report of First Survey of Subject Matter Experts). We found that the SMEs confirmed our hypotheses and that there was agreement among SMEs in their ability to identify, and evaluate, specific attributes that could be used to separate tactical situations into meaningful categories. Though additional attributes were added after a subsequent survey (see Appendix B: Report of Second Survey of Subject Matter Experts), the initially identified attributes were:

- **Anchored or Unanchored Flanks**, with the following definitions: flank: either end of a mobile or fortified military position; anchored (or refused) flank: a flank that is attached to or protected by terrain, a body of water, or defended fortifications and Unanchored (or Open) Flank: a flank that is not protected; also said to be "in the air."
- **Interior Lines**, defined as: "The military circumstance of either being able to move over a shorter distance to execute maneuvers and effect reinforcements than the enemy or possessing a more efficient transportation method or faster units than the enemy. Interior Lines are defined relative to those of the enemy; consequently they can be

categorized as either interior (shorter distance between flanks than the distance between the enemy's flanks) or exterior (greater distance between flanks than the enemy's flanks.)" (Yates)

- **Avenue of Approach also Avenue of Attack**, defined as, "a ground route of an attacking force of a given size leading to its objective or to key terrain in its path." (Joint Publication 1-02: Department of Defense Dictionary of Military and Associated Terms.)
- **Avenue of Retreat**, defined as, "the ground route of a retreating defending force. (Joint Publication 1-02: Department of Defense Dictionary of Military and Associated Terms.)
- **Choke Point**, defined as, "a choke point is a geographical feature on land such as a valley or defile which an armed force is forced to pass, sometimes on a substantially narrower front, and therefore greatly decreasing its combat power, in order to reach its objective." (Wikipedia, Choke point)

We next proceeded to design a series of algorithms (see Chapter 4) that produced appropriate values for these attributes in various tactical situations.

To test these algorithms, and for future use with the second hypothesis, we began creating a database of historical tactical situations. The source of this database was the definitive work by Esposito, "The West Point Atlas of American Wars," in two volumes that has been used as a textbook at the U. S. Military Academy.¹

1. The arduous process of scanning the images, converting the images into elevation, terrain and topographical layer maps for TIGER and inputting unit information was underwritten, in part, by a seedling grant from DARPA (Defense Advanced Research Projects Agency).

We next proceeded to run our algorithms on the dataset of 20 historical tactical situations. The resulting output allowed us to manually find similarities between historical situations which we then presented to SMEs for validation (see Appendix B: Report of Second Survey of Subject Matter Experts). In addition to validation of our first four attribute classification algorithms, the SMEs suggested two more attributes:

- **Ratio of Weighted Strength**, defined as the strength of each unit in REDFOR² multiplied by the appropriate Operational Lethality Index (OLI) as defined by Dupuy over the strength of each unit in BLUEFOR multiplied by the appropriate OLI. (Dupuy)
- **Weighted Slope of Attack**, defined as the slope of the elevation that must be traversed by BLUEFOR units to attack the REDFOR units weighted by the OLI for each BLUEFOR unit.

We then proceeded to implement the CLASSIT clustering system (see Chapter 2) and processed the dataset of historical scenarios. This resulted in a number of distinct clusters (see Appendix D) of similar tactical situations. This allowed us to produce five hypothetical tactical situations that represented five distinct clusters (for example, tactical situations in which BLUEFOR had restricted Avenues of Approach, tactical situations in which REDFOR had interior lines, etc.) . These five hypothetical situations were then entered into TIGER to confirm that they were placed into the appropriate cluster.

2. Throughout we use the standard military terms REDFOR to mean the Red Forces and BLUEFOR to mean the Blue Forces. In addition, for expository purposes, TIGER assumes that REDFOR is on the defensive and BLUEFOR is attacking.

Lastly, a survey of SMEs was conducted (see Appendix C: Report of Third Survey of Subject Matter Experts) to compare the best match by TIGER of a hypothetical tactical situation to its historical database with the choice of the SMEs to confirm hypothesis #2.

In 1950 Alan Turing famously wrote, “I believe that in about fifty years' time it will be possible, to programme computers ... to make them play the imitation game so well that an average interrogator will not have more than 70 per cent chance of making the right identification after five minutes of questioning.” (Turing) If the imitation game is restricted to the field of tactical analysis, TIGER easily passes Turing's test and matches the SMEs response 80% of the time.

An overview of the research cycle appears in Figure 1, below:

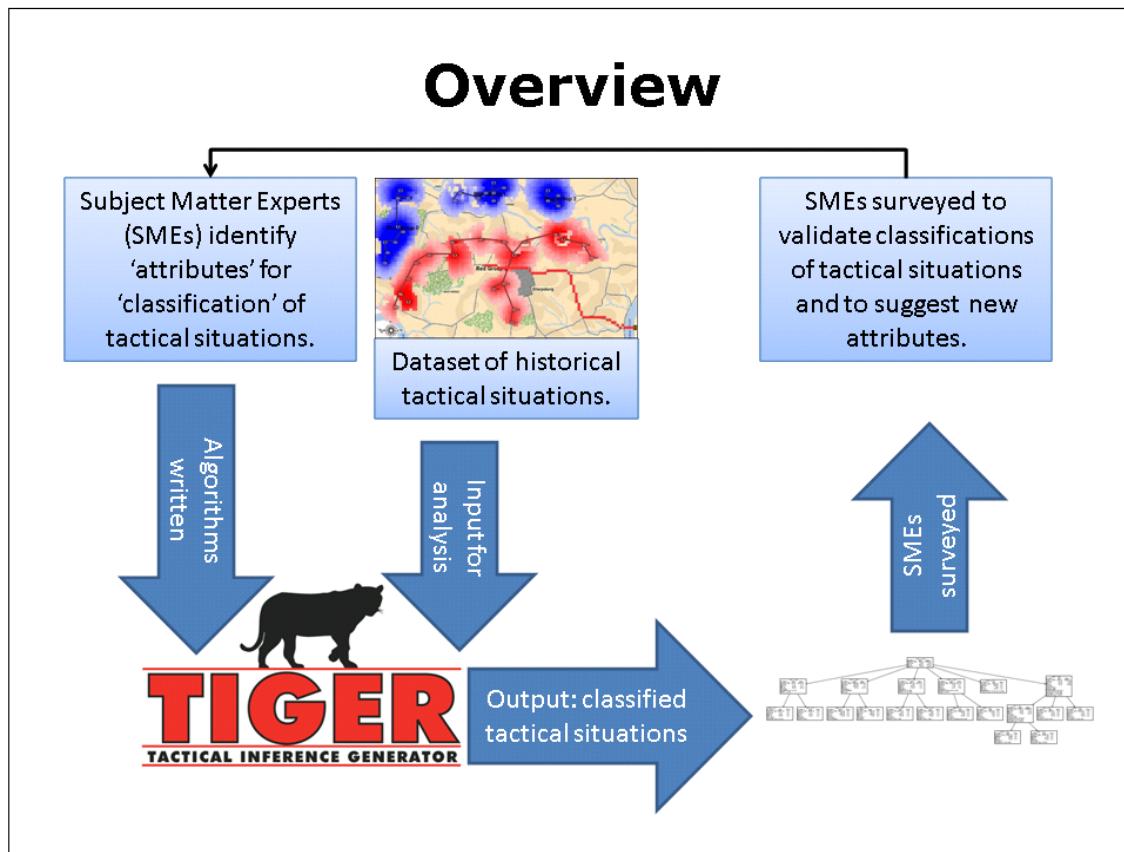


Figure 1: Overview of TIGER research process. Note that the Subject Matter Experts (SMEs) are involved throughout the process, both identifying important attributes for classification, validating the values produced by the algorithms as well as validating the final classification output.

CHAPTER II: COBWEB/CLASSIT AND LITERATURE REVIEW

Categorization has been described as one of the most basic cognitive functions. (Cortner and Gluck) Research in the area of ‘categorization’ is over thirty years old, and, perhaps not surprisingly, originated in the field of psychology. However, since the 1980s it has been associated, in part, with unsupervised machine learning, as in the work of Fisher, Gennari and Langley on the COBWEB and CLASSIT programs.

Consider a ‘domain’ of ‘objects’; for example, the domain of four-legged mammals might include cats, dogs, squirrels, elephants and horses, which we call ‘objects’ or ‘instances’ (we use the terms interchangeably, and later, we will also use the term ‘tactical instance’ as an object for classification). Given a set of these instances in some random order, how can we group them in a meaningful way by their intrinsic characteristics? To do so, we will need an algorithm that classifies the objects into these meaningful groups and a data structure to represent these groups. COBWEB and CLASSIT provide solutions for both of these problems.

In order to create meaningful categories, we need to identify certain ‘attributes’ that can be used to describe each instance. For example, attributes used to describe the domain of four-legged mammals might include ‘size of head’, ‘length of neck’, ‘length of tail’, etc. (Gennari and Langley) Likewise, attributes used to describe types of animals might include ‘number of chambers of the heart’, ‘type of skin’ and ‘method of body temperature regulation’. (D. H. Fisher) Indeed, within our context an object is merely a collection of attributes.

Every object within the domain that we wish to categorize contains the same number of attributes.

The determination of appropriate attributes is crucial to the meaningful classification or categorization of a domain. In Chapter 5 we present the results of three surveys conducted of Subject Matter Experts (SMEs) that validate the ‘appropriateness’ of the attributes that we have selected to represent instances in the domain of tactical situations and, as shown in Figure 1, above, we believe that it is crucial that SMEs are involved throughout the process of identifying meaningful attributes for classification, validating the attribute values produced by our algorithms, and validating the final classification output.

Consider, for example, if we used only the attribute of ‘fur color’ in our domain of ‘four-legged mammals’: a dog with brown fur would be classified as similar to a horse with the same color hair. This is clearly not a meaningful attribute for this domain. If, however, the inappropriate attribute of ‘fur color’ was but one of a number of attributes (the rest being more appropriate), the inappropriate attribute could have the effect of ‘diluting’ the value of the appropriate attributes which could result, again, in meaningless classifications.

Assume that we have constructed a classification of objects placed in a corresponding data structure based on meaningful attributes that have been validated by SMEs. The relationships (similarities and dissimilarities) of the objects in are clearly apparent, based on the relationship of these objects in the data structure. What sort of problems could benefit from the application of this technique? What are the advantages of this approach to certain kinds of problem solving?

Within our research area of computational military reasoning (or computational tactical planning) we wish to analyze extraordinarily complex environments and arrive at some conclusions, which will facilitate decision making, within a short period of time. It is neither practical, nor possible, to calculate every possible outcome of a tactical situation and current methods of computational tactical planning are extremely slow. Indeed, one of the goals of the current IPTO/DARPA project, Deep Green, is to reduce these calculations from the current 120 minutes to less than 3 minutes. (J. Surdu)

Using a classification system allows us to quickly see the *gestalt* of a new tactical situation and to compare it to similar tactical situations in our database of previously analyzed and classified situations. For example, if a new tactical situation is classified alongside a previously observed and analyzed tactical situation we can draw upon our knowledge of the previously analyzed tactical situation to make certain inferences and assumptions that will greatly speed up the decision making process.

Conceptual clustering and hierarchical classification trees

The term “conceptual clustering” is more commonly used in computer science and a “conceptual clustering system” is defined as a system that accepts a set of object descriptions and produces a classification scheme over the observations. These systems are “unsupervised” in that they do not require a “teacher” to seed the system with pre-classified examples but are driven by an evaluation function (commonly called a ‘category utility function’) to, “discover classes with ‘good’ conceptual descriptions. Thus, conceptual clustering is a type of *learning by observation...*” (emphasis in the original). (D. H. Fisher)

Furthermore, some conceptual clustering systems are incremental, in that they continually ‘learn’ as more data are added.

Conceptual clustering is a method in computer science in which a hierarchical classification tree is incrementally constructed from a set of instances. Instances are incorporated sequentially into the classification tree. As each instance is presented to the algorithm that builds the tree, the category utility function is employed to determine the ‘best’ node to place the instance under consideration. Instances that share similar characteristics will be placed within the same subtree; while instances that are very dissimilar will only share a common root node (all objects within a tree share a common root node). Two instances that share a common parent will be more similar than two instances that share only a grandparent. The algorithm is also capable of creating a new node in which to place the instance, to merge two nodes or to split a node. The algorithm is recursive which allows for an instance to descend the tree until it finds the node that returns the highest score from the category utility function. The algorithm is also order dependent; presenting the instances to the algorithm in a different sequence may well produce a different tree.

This work is driven by the category utility hypothesis which states that, “a category is useful to the extent that it can be expected to improve the ability of a person to accurately predict the features of instances of that category.” (Corter and Gluck)

The classification tree is initially empty and consists of only an empty root node. Objects are presented sequentially and are first incorporated into the root node, which, like all nodes in the classification tree, maintains a record of all objects that have passed through it. Consequently, the root node always represents

the complete set of objects that have been classified so far; indeed, children of any node represent subsets of the instances stored at that node.

Subsets (or sub-trees) of the classification tree share a similarity of attributes. Instances that have been placed within the same node are the most similar (in CLASSIT their similarity is described by σ , the standard deviation). Instances in nodes that share a parent are more similar than nodes that only share a grandparent, but less similar than instances that share a node. Nodes from disjoint subsets are the least similar (or the most dissimilar).

While COBWEB, CLASSIT and TIGER retain different information in the nodes (TIGER, for example, maintains a pointer to a file that contains detailed information about each tactical instance), they all share similarities in their data structures. Each node must contain a 'count' of the number of objects in the node (this is used to calculate prior probabilities). Each node must contain data necessary to calculate probabilities used by the category utility function (the specific data is different for COBWEB than it is for CLASSIT and TIGER as we will see below). Lastly, each node must contain a pointer to its parent to maintain the tree structure, itself.

As each object is introduced into the root node, the following actions are considered and the resulting score of the category utility function from the action is recorded:

- The object is added to an existing node (all children of the parent node are evaluated)
- The object is placed in a new node
- The two top-scoring nodes are combined into a single node, and the new object is added to it
- A node is divided into several nodes, with the new object added to one of them

The action with the highest resulting category utility score is then chosen and the options are evaluated again at the node that receives the new object. In this way each object ‘descends’ the tree until it is situated in the node that it is most similar to. The process of combining and dividing nodes (as well as promoting and demoting nodes while ‘percolating’ the new object down the tree) constructs the hierarchical classification tree. It is clearly a greedy strategy, one where different presentation orders result in different classification trees (Appendix D shows the order in which all objects were presented for classification to TIGER).

Below, we discuss the differences in the implementation of the category utility functions and implementation of COBWEB and CLASSIT.

COBWEB

The COBWEB algorithm was introduced by Fisher in his paper, “Knowledge Acquisition via Incremental Conceptual Clustering” in 1987. In it he introduces the basic algorithm for construction of the hierarchical classification tree and the category utility function that drives it. It is primarily of interest to us because it forms the basis of CLASSIT, which is implemented in TIGER.

COBWEB attributes take on only one value and only nominal attributes are allowed. For example, an attribute, in the domain of ‘animals’ might be ‘body temperature’ and the possible values would be ‘unregulated’ or ‘regulated’. (D. H. Fisher) The integer counts needed to calculate the attribute value probabilities³ are stored in each node.

3. In COBWEB category utility can be computed from $P(C_k)$ of each category in a partition and $P(A_i = V_{ij}|C_k)$ for each attribute value where an attribute value is $A_i = V_{ij}$. (D. H. Fisher)

COBWEB's restriction to nominal attributes makes it impractical for our needs in TIGER (for example, it is not sufficient for us to categorize a tactical position as simply having 'interior lines' or 'exterior lines', but rather we need to describe the extent of the advantageousness of the position). COBWEB's category utility function is designed for evaluating placement of objects with nominal attributes values and therefore is also not applicable to our needs and consequently will not be shown here.

However, the COBWEB algorithm is used both by CLASSIT and TIGER and the expanded algorithm as it appears in Gennari is below:

The COBWEB algorithm

Input: The current node N of the concept hierarchy

 An unclassified (attribute-value) instance I .

Results: A concept hierarchy that classifies the instance.

Top-level call: Cobweb(Top-node, I)

Variables: C , P , Q , and R are nodes in the hierarchy.

U , V , W , and X are clustering (partition) scores.

Cobweb(N, I)

If N is a terminal node,

Then Create-new-terminals(N, I)

 Incorporate(N, I).

Else Incorporate(N, I).

For each child C of node N ,

 Compute the score for placing I in C .

 Let P be the node with the highest score W .

 Let R be the node with the second highest score.

 Let X be the score for placing I in a new node Q .

 Let Y be the score for merging P and R into one node.

 Let Z be the score for splitting P into its children.

If W is the best score,

Then Cobweb(P, I) // place I in category P

Else if X is the best score,

Then initialize Q 's probabilities using I 's values

 // place I by itself in the new category Q

Else if Y is the best score,

Then let O be Merge(P, R, N).

```

                                Cobweb( $O, I$ ).
Else if  $Z$  is the best score,
                                Then Split( $P, N$ ).
                                Cobweb( $N, I$ ).

```

Note that “If N is a terminal node” always occurs when I is the first instance. Also, note that COBWEB is recursive and it is precisely this recursive nature that pushes the instance I down the tree, creating, splitting or merging nodes as necessary, until it rests in the most similar node. COBWEB terminates when either I is the only instance in the (new) node or the score is less than the *cutoff* value (see below).

The COBWEB algorithm “can be viewed as hill climbing through a space of classification trees.” (D. H. Fisher) Hill climbing is a greedy search in which local options are tried, an evaluation function is used to score each option, the best option is chosen, and the entire process is repeated until no more progress can be made.

CLASSIT

Two years after COBWEB, Gennari, Langley and Fisher introduced CLASSIT, which is a modification of COBWEB. Indeed, the differences between the COBWEB and CLASSIT are few and primarily consist of CLASSIT’s ability to accept real-valued attributes and a simplification of the category utility function. CLASSIT also introduces the concept of *acuity* which is necessary to prevent division of $1/\sigma$ when $\sigma = 0$ and *cutoff* which restricts the depth of the classification tree.⁴

4. We follow Gennari, et. al, in defining *acuity* as 1.0. Because of this it is crucial that no attribute produce a value in the range of $[0,1]$ as this value will be lost when a node possesses only one instance and *acuity* replaces the value of σ which would be 0. Any algorithm described in Chapter 4 that produces a value in the range of $[0,1]$ goes through scaling before the value is stored for classification.

We introduce the CLASSIT category utility function here:

$$CU = \frac{\sum_k^K P(C_k) \sum_i^I 1/\sigma_{ik} - \sum_i^I 1/\sigma_{ip}}{K}$$

where I is the number of attributes, K is the number of classes (or nodes) and σ is the standard deviation. The first term in the numerator is the prior probability, based on class size, that the instance is a member of the class C_k . The second term is the standard deviation for a given attribute in a given class and the final term is the standard deviation for a given attribute in the parent node.

Like COBWEB, CLASSIT is driven by the same algorithm in which one of four operations is performed as an instance descends the classification tree. Unlike COBWEB, CLASSIT, because it utilizes the standard deviation of an attribute value in the category utility function, must store the count of instances, and the sum and the sum of the square of the attribute values in each node. These values, in effect describe a continuous normal distribution (bell-shaped curve) for each attribute. (Gennari and Langley) Thus, CLASSIT implicitly assumes that attribute values are normally distributed which may not always be the case in practice.

CLASSIT is not an optimal solution algorithm; indeed to do so, using a ‘brute force solution’ that considers all possible tree structures on N instances would result in an algorithm running in $O(n!)$. As currently implemented, CLASSIT runs in $O(n^2)$.

A Classification Tree Example

We provide, below, a simple step by step example of how a classification tree is built. Consider the domain of “pets found in the author’s house”:

Table 1: Pets found in the author’s house

Name:	Weight:	Height:	Length:	Type:
Zoe	55.7	24.0	28.5	Dog
Sonny	12.5	10.0	11.5	Cat
Smokey	14.5	12.0	17.5	Cat
Shelby	62.5	26.0	32.5	Dog
Peter	16.5	13.5	19.5	Cat

We will ‘introduce’ each of the ‘instances’ of ‘pet’ in the order in which they are presented above (Zoe, Sonny, Smokey, Shelby and Peter) and observe the results. The first ‘instance’ is Zoe and following the COBWEB algorithm, it will appear as just the root node (note that the means for all the attributes are just the instance’s values and sigma is set to the minimum value, 1.0, due to acuity)⁵:

Attribute	Mean	Sigma	Pets in Category
Weight	55.70	1.00	Zoe
Height	24.00	1.00	
Length	28.50	1.00	

Figure 2: After incorporation of the first instance, “Zoe”.

5. Within each node we store the sum of each attribute, the sum of the squares and the ‘count’ or number of instances within the node. Mean and the standard deviation are calculated ‘on the fly’ and then displayed.

We now introduce Sonny, first placing it in the root node. Using the category utility function we determine the score of the two options available: place Sonny in the same node as Zoe or place Sonny in its own separate node. Placing Sonny in its own node is the higher score which results in the following tree:

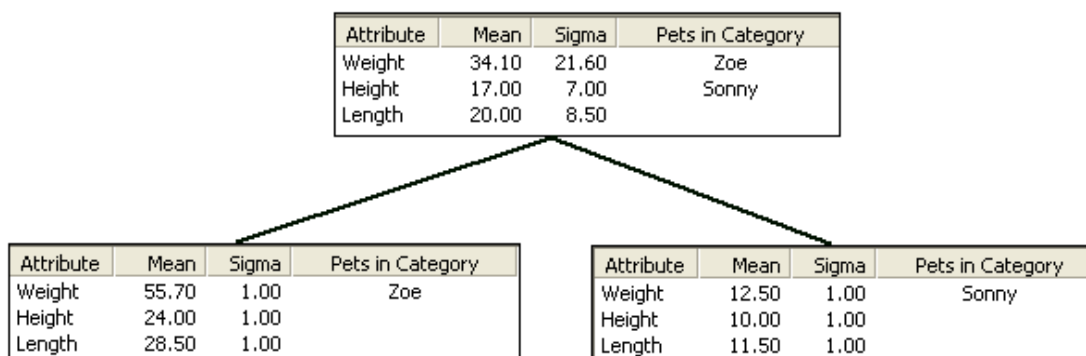


Figure 3: After incorporation of the second instance, “Sonny”.

Note how the root node includes both Zoe and Sonny. We now introduce Smokey. As with every instance, it is first incorporated into the root node and three possible options are evaluated: place Smokey in the same node as Zoe, place Smokey in the same node as Sonny or place Smokey in its own node. The option with the highest score returned by the category utility function is to place Smokey in the same node as Sonny. The COBWEB algorithm is recursive and it now evaluates the options available after Smokey has been placed in the same node as Sonny (note that the algorithm does not consider any options involving the root node or the node with Zoe): placing Smokey and Sonny in two new ‘leaves’ or not doing anything. The first option returns the highest score from the category utility function and the tree now looks like this:

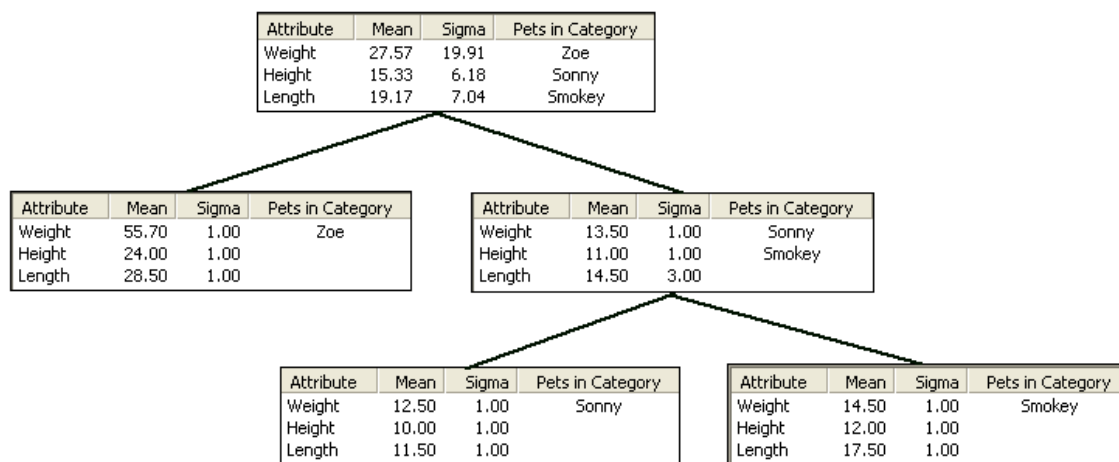


Figure 4: After incorporation of the third instance, “Smokey”.

Note that the path that Smokey took through the tree started with the root, where it was added, and then it ‘percolated down’ to share a node with Sonny (where it was, again added to the node) and then, because of the differences in the length attribute it was placed in its own node.

We now introduce Shelby. Like Smokey, previously, Shelby is first introduced into the root node and then three options are evaluated: place Shelby in the same node as Zoe, place Shelby in the same node as Sonny/Smokey, or put Shelby in a new node. The option with the highest score returned by the category utility function is to place Shelby, temporarily, in the same node as Zoe. Like the previous example, the algorithm then evaluates all options from this node: placing Zoe and Shelby in new separate nodes or stopping. Again, note, that no operations involving the root, the Sonny/Smokey node nor the Smokey and Sonny nodes, individually, is even considered. The option with the highest score returned by the category utility function is to place Zoe and Shelby in separate nodes with a common parent:

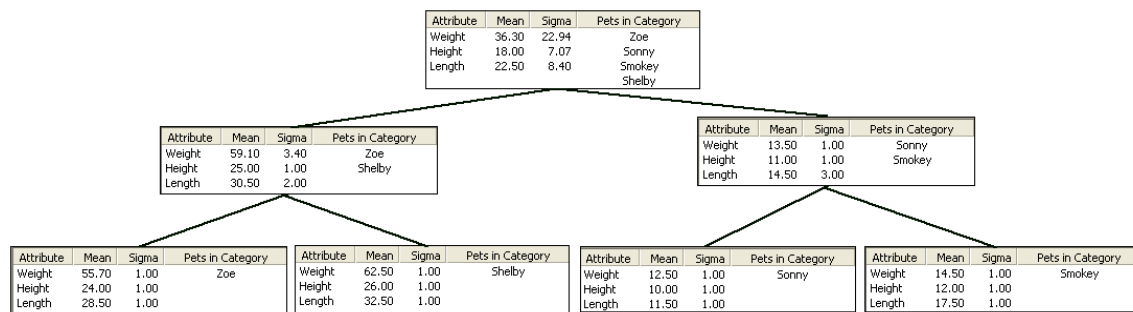


Figure 5: After incorporation of the fourth instance, “Shelby”.

Lastly, we introduce Peter. Like its predecessors, Peter is first incorporated into the root and three options are evaluated: add Peter to the Zoe/Shelby node, add Peter to the Sonny/Smokey node or create a new node. The highest score returned by the category utility function is to add Peter to the Sonny/Smokey node. The algorithm is called again, evaluates options only from the Sonny/Smokey/Peter node (again ignoring the root node, the Zoe/Shelby node, the Zoe node and the Shelby node) and the highest scoring option, placing Peter in the Smokey node is performed. The algorithm is called again, now only evaluating options from the Smokey/Peter node and ignoring all others. The option of placing Smokey and Peter in different nodes is evaluated but the score returned by the category utility function is less than the cutoff value (1.0) and so the algorithm terminates leaving Smokey and Peter in the same node:

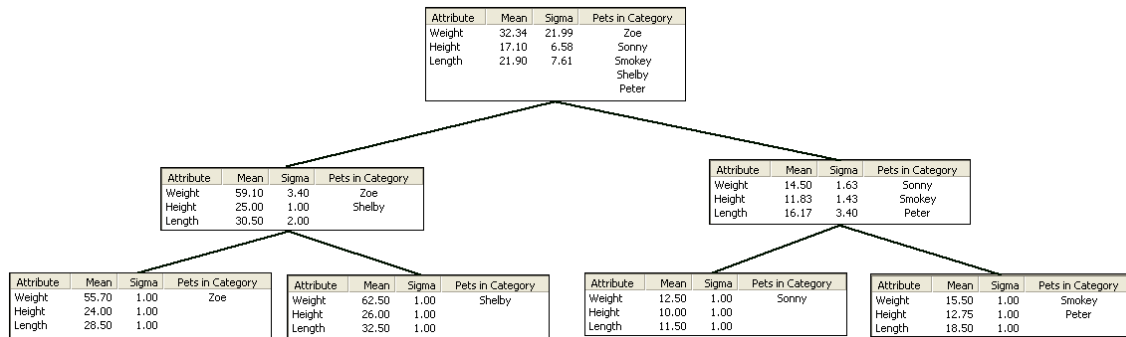


Figure 6: After incorporation of the fifth instance, “Peter”.

Clearly these two pets (Smokey and Peter) are very similar based on weight, height and length.⁶ Indeed, the differences of all three attributes are less than acuity and, consequently, sigma for the Smokey/Peter node is set to 1.0, the minimum value.

There are, of course, two other significant observations from this example: all the dogs share a common node (Zoe/Shelby) and all the cats share a common node (Sonny/Smokey/Peter). It is also important to note that the algorithm, itself doesn’t indicate that Zoe and Shelby are dogs or that Sonny, Smokey and Peter are cats. The graphic representation of the nodes shows that there are two distinct categories and it is a human SME that identifies the two categories as cats and dogs.

Furthermore, this example works because an SME, familiar with all the instances, determined the attributes used for classification. Consider the introduction of a new instance, a small miniature dachshund named Otto that was about the same weight, length and height as Sonny, Smokey and Peter. If Otto

6. They are, in fact, overweight domestic American cats.

was introduced into this classification tree he would be classified on the Sonny/Smokey/Peter side of the tree. However, an SME familiar with the domain of “pets in the author’s house” would know this and select other attributes (possibly length of canine teeth, amount of tail wagging, time spent cleaning oneself, time spent watching birds out the window, etc.). This demonstrates the importance of including SMEs within the process of determining meaningful attributes for classification.

Lastly, we display a screen capture of TIGER after having ‘consumed’ all the instances of our example:

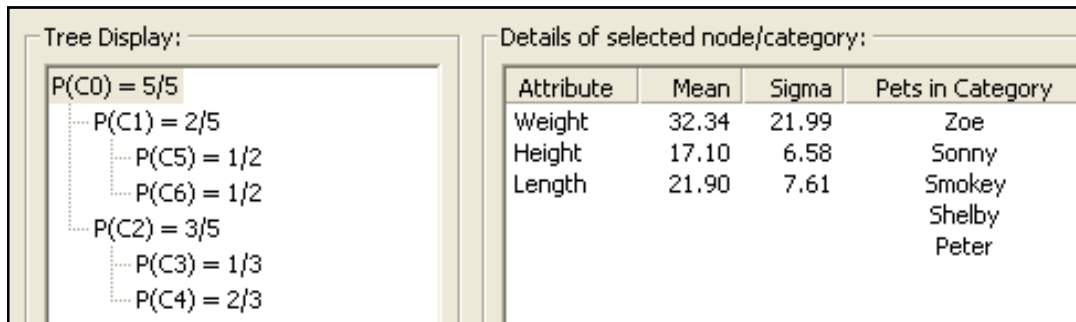


Figure 7: A screen shot of TIGER after classifying the domain of ‘pets’.

Note that the ‘Tree Display’ on the left of Figure 7, above, matches the graphical depiction of the tree from our example.

CHAPTER III:

TIGER

Overview

TIGER (an acronym for Tactical Inference GenERator) is a test bed program for our research. It is written in C++ and runs on any Windows™ XP or better computer. It is a fully functional program, with a graphical user interface, that supports placing military units in a three-dimensional environment, applying various experimental algorithms and outputs results via HTML, graphics displayed on the screen, graphical tree structures and text documents.

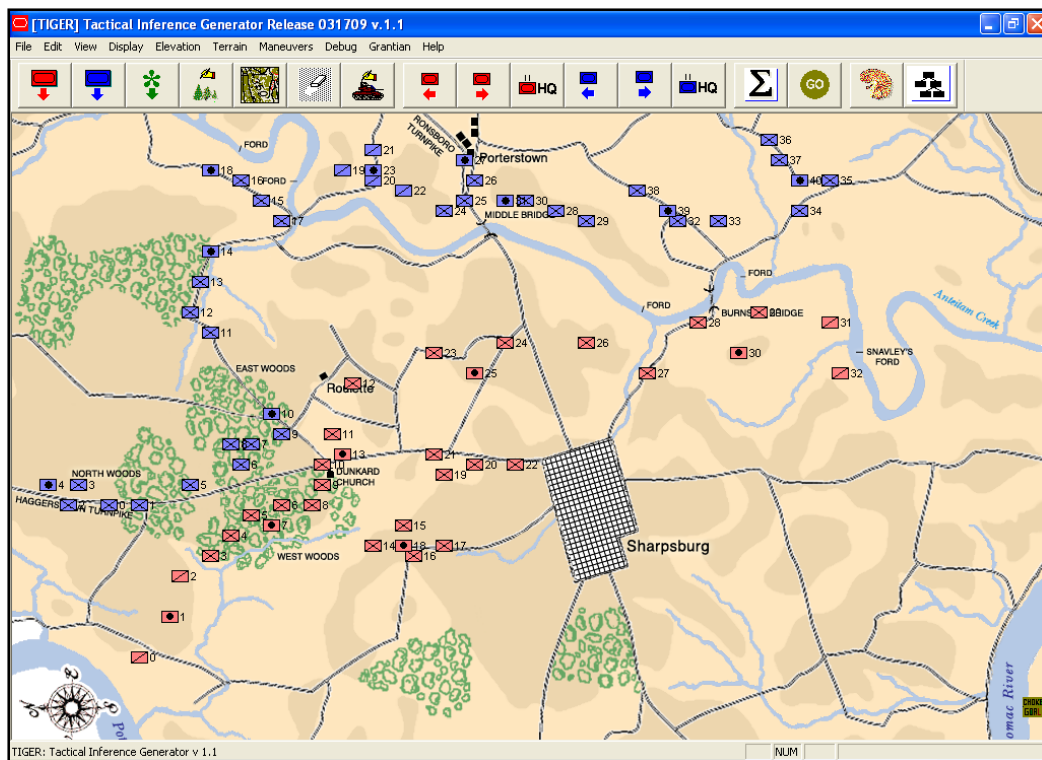


Figure 8: TIGER (screen capture).

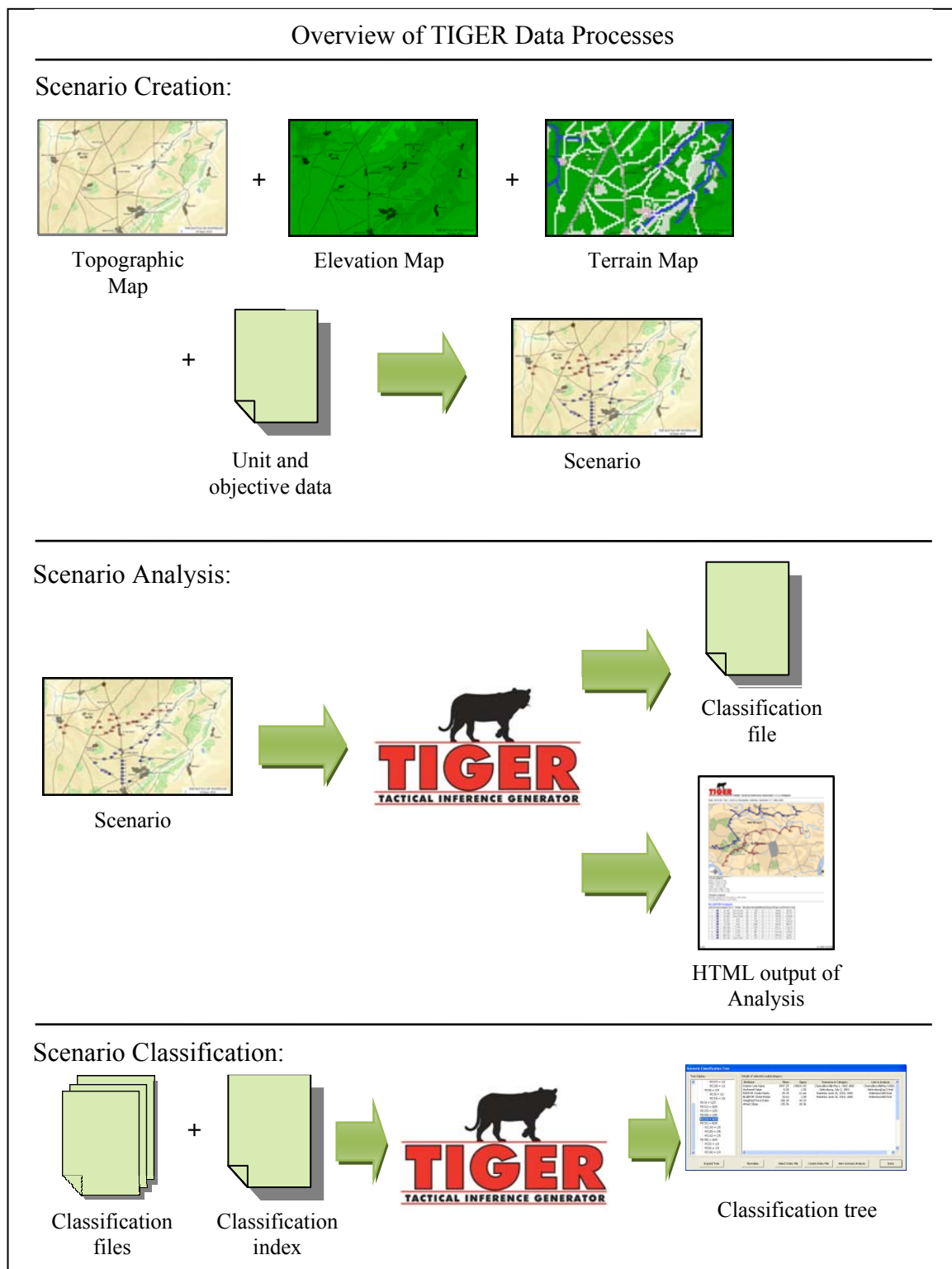


Figure 9: Overview of TIGER data processes.

Visually, TIGER looks and operates like a standard Windows™ application. The scenario is displayed in a window that can be sized, minimized or maximized. Above the scenario window is a floating/docking toolbar that can be positioned anywhere on the screen (see Figure 10). At the top of the window are a series of pull-down menus that are described in detail below.

Conceptually, TIGER consists of two sections: one section that facilitates the creation of tactical situations (scenarios) and another section that performs various analyses of the scenario (or scenarios) and outputs the results.



Figure 10: The TIGER toolbar.

The Toolbar

The user accesses various functions of the toolbar by clicking on the icons.

The functions of the toolbar, from left to right, are:

- Place REDFOR units
- Place BLUEFOR units
- Place objectives (used for assigning objectives for offensive maneuvers (see (Sidran and Segre)) and for positioning REDFOR retreat area (see Restricted Avenues of Approach, Chapter 4, below)
- Display the 'terrain layer' and activate terrain drawing tool
- Display the 'elevation layer' and activate elevation drawing tool
- Erase all units, objectives, terrain and elevation
- Edit unit type values
- Cycle through REDFOR units (in descending order) and display the line of sight (LOS) for the active unit
- Cycle through REDFOR units (in ascending order) and display LOS for the active unit
- Show the sum of all LOS for all REDFOR units
- Cycle through BLUEFOR units (in descending order) and display LOS for the active unit
- Cycle through BLUEFOR units (in ascending order) and display LOS for the active unit
- Show the sum of all LOS for all BLUEFOR units

- Calculate optimal paths for BLUEFOR based on previously selected offensive maneuver
- Step units through movement paths
- Calculate 'predicate statements', generate HTML code and launch browser
- Perform CLASSIT clustering analysis and write the .CLA file to disk

Scenario Creation

A scenario consists of four layers of data (topographical overlay, terrain overlay, elevation overlay and units). The scenario designer begins by starting with a 'clean slate' by selecting the Erase icon from the toolbar. Next, the designer selects Edit Scenario from the Edit pull down menu. The Scenario Information dialog box is displayed (see Figure 11, below). The designer then enters appropriate information about the scenario and selects a topographical map (in .BMP) format.

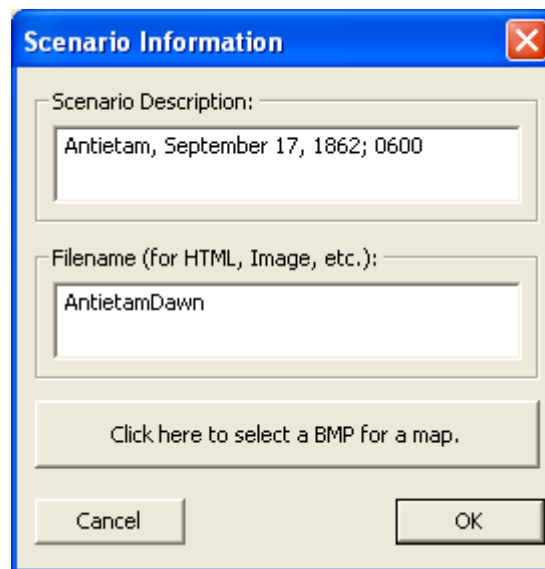


Figure 11: The Scenario Information dialog box.

Though elevation data can be entered by hand using the elevation tool, TIGER facilitates the procedure by allowing for the importation of a BMP file in which the green value of the RGB value for each pixel is extrapolated into an elevation in meters (for example, a pixel with the RGB value of 0,100,0 would be converted to an elevation of 100 meters at the corresponding map location).

Design of the terrain layer is also facilitated by TIGER's ability to import a BMP file and extrapolate rivers and lakes from any pixel that has a value for blue in the RGB triplet. Other terrain features are entered by hand; however the topographical map remains as a transparent overlay which facilitates the placement of terrain features (see Figure 12, below).

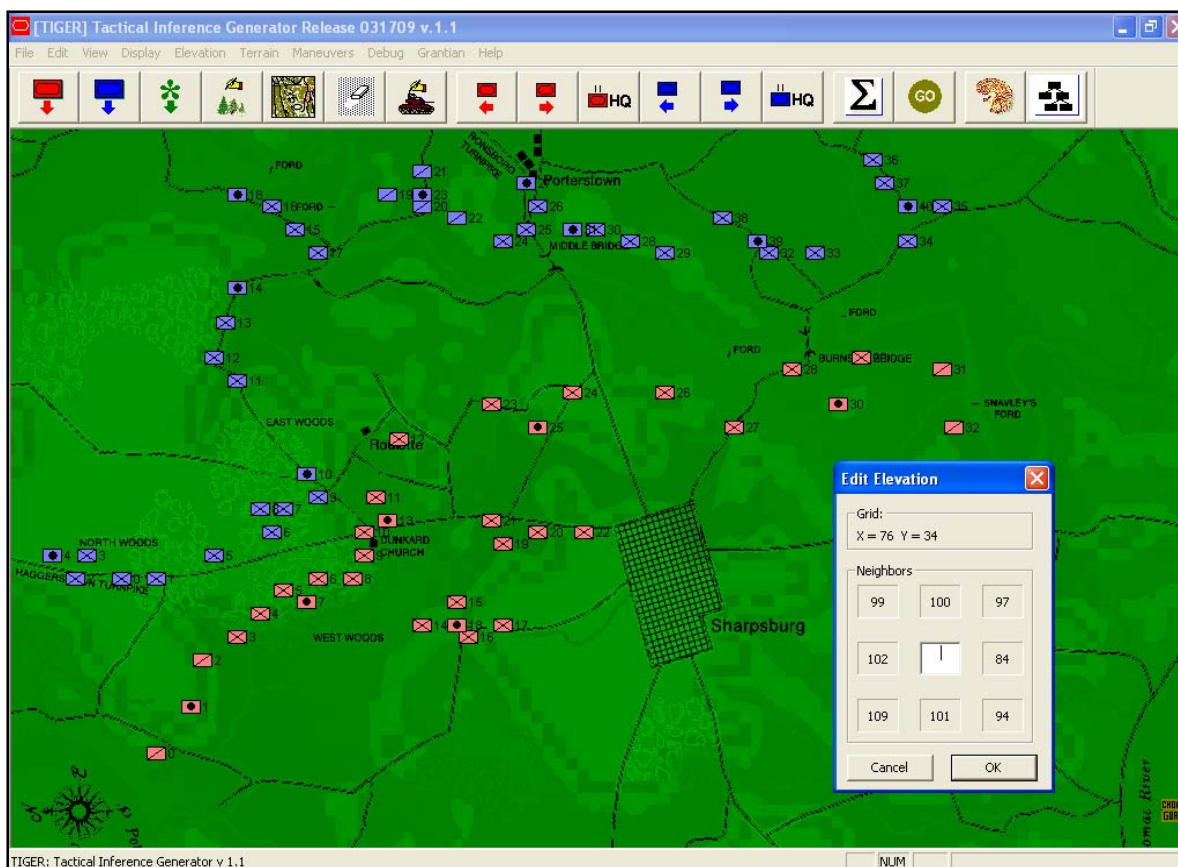


Figure 12: Elevation layer with manual elevation tool displayed.

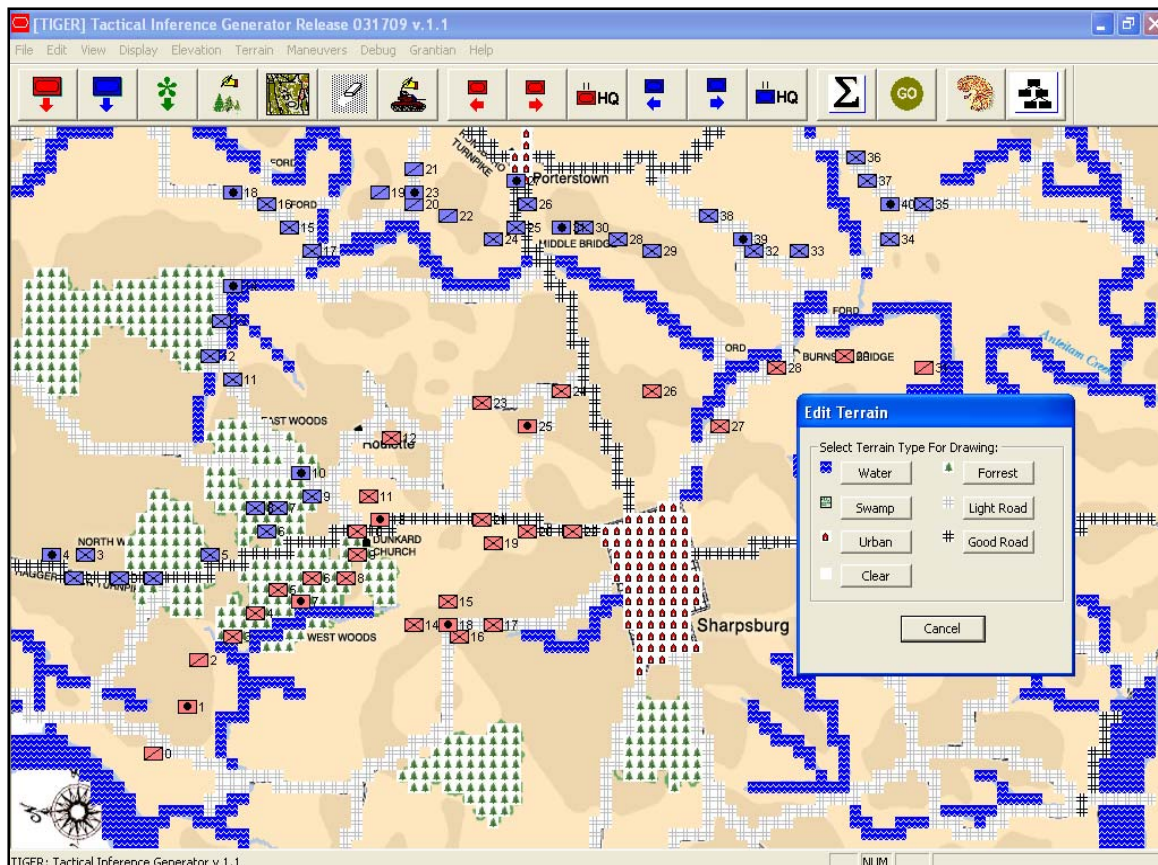


Figure 13: The terrain layer with Terrain Editing tool displayed.

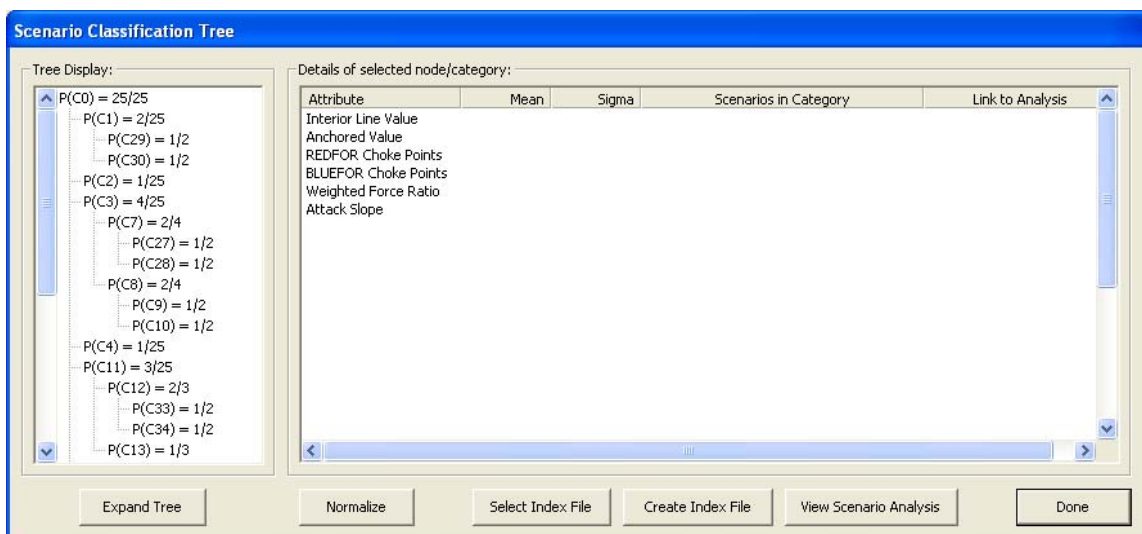


Figure 14: The Scenario Classification Tree dialog box.

The final step of scenario creation is the placement of the icons representing military units on the map. This is accomplished by first clicking on either the Place REDFOR or Place BLUEFOR unit icon in the Toolbar and clicking on the map. A dialog box appears that allows the user to select the desired unit type (Armor, Infantry, Cavalry, Artillery, Mechanized Infantry or ‘Special’). The designer then enters the number of troops in the unit. Other options, available from the pull-down menus allow the designer to specify the Operational Lethality Index (OLI) values (Dupuy), LOS options, etc.

Lastly, the designer can save the completed scenario (or load a previously saved scenario) by selecting the appropriate option from the File menu.

Scenario Analysis

While TIGER also performs offensive maneuver calculations that were the subject of a previously published paper, we are concerned, here, with its analysis for classification. These functions (described in Chapter 4, below) are handled automatically when the user clicks on the Perform CLASSIT clustering analysis icon in the toolbar and the results are written to disk. To examine the classification of a dataset, the user selects Display → Classification Tree from the appropriate pull-down menu and selects the desired file from the disk. This dialog box (Figure 15, below) allows the user to explore the classification tree in detail and launch a browser and display the HTML file associated with a particular scenario.

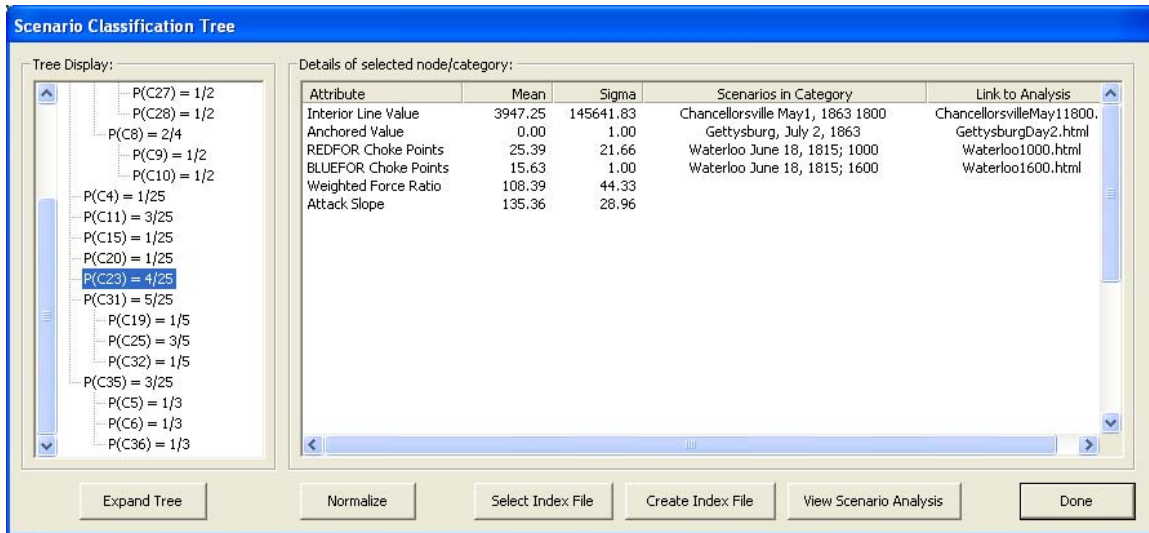


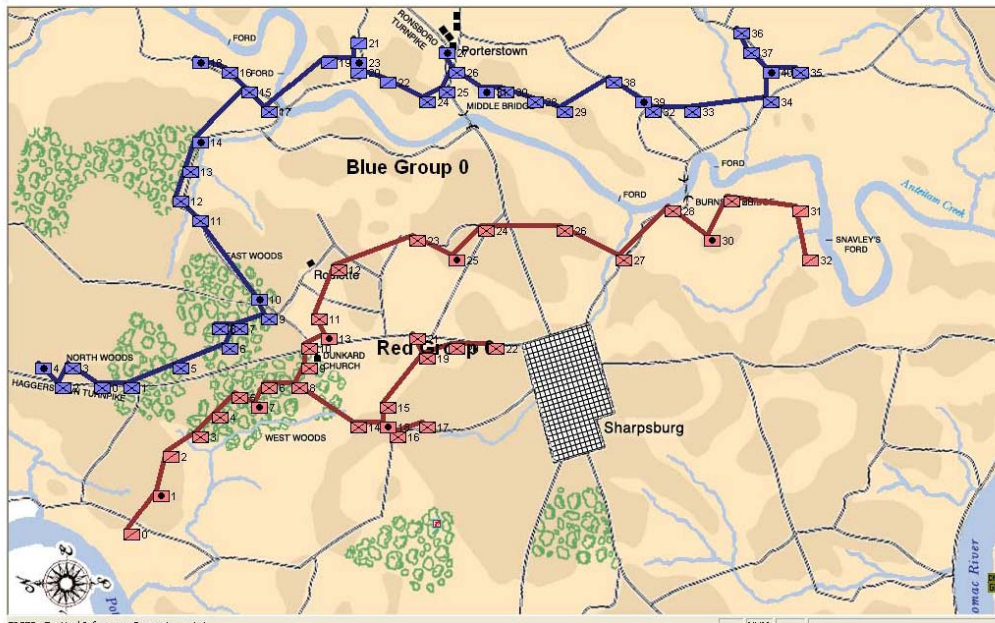
Figure 15: Example of node data displayed.

A user can also generate HTML output by clicking on the ‘generate predicate statements’ button in the toolbar (see Figure 16, below).



TIGER: Tactical Inference Generator v 1.1 Analysis

Date: 03/19/09. Time: 19:40:14. Description: Antietam, September 17, 1862; 0600



TIGER: Tactical Inference Generator v 1.1

Terrain analysis:

Water: 9.05 % of map.
Swamp: 0.00% of map.
Forest: 6.12% of map.
Urban: 1.41% of map.
Light Road: 9.98% of map.
Good Road: 2.78% of map.

Elevation analysis:

Elevation ranges from 75 meters to 125 meters.
The average elevation is 94 meters.

BLUEFOR Analysis:

Unit ID	Type	Location (X,Y)	Terrain	Elevation	Strength	Morale	Group	Threat Level	Friend Level
0	Blue	90, 380	Good Road	125	1029	40	0	-189.89	653.86
1	Blue	120, 380	Good Road	125	825	40	0	-358.83	619.76
2	Blue	50, 380	Good Road	125	815	40	0	-165.98	1232.82
3	Blue	60, 360	Clear	125	875	40	0	-165.28	615.87
4	Blue	30, 360	Clear	125	1128	40	0	-150.34	1494.29
5	Blue	170, 360	Clear	125	2590	40	0	-346.93	860.00
6	Blue	220, 340	Forest	125	2159	40	0	-427.01	1004.12
7	Blue	230, 320	Forest	125	909	40	0	-1017.57	1162.01
8	Blue	210, 320	Forest	125	681	40	0	-1007.38	1219.63
9	Blue	260, 310	Forest	116	925	40	0	-1585.02	25.84
10	Blue	250, 290	Light Road	125	1974	40	0	-1011.22	845.02

Figure 16: HTML output of TIGER analysis of Antietam scenario (continued next two pages).

11		190, 210	Light Road	93	1429	40	0	-60.37	1140.97
12		170, 190	Light Road	100	1145	40	0	-30.78	1217.86
13		180, 160	Light Road	97	1450	40	0	-56.21	764.15
14		190, 130	Light Road	80	564	40	0	-280.16	939.90
15		240, 80	Light Road	80	2200	40	0	-247.62	305.84
16		220, 60	Light Road	80	1466	40	0	-410.78	1493.27
17		260, 100	Light Road	82	1833	40	0	-285.22	699.26
18		190, 50	Light Road	78	1128	40	0	-44.07	1579.03
19		320, 50	Clear	96	1650	40	0	-180.66	1590.22
20		350, 60	Light Road	82	1600	40	0	-72.18	1336.71
21		350, 30	Light Road	81	570	40	0	-71.87	2118.49
22		380, 70	Clear	100	1400	40	0	-228.71	498.75
23		350, 50	Light Road	82	1128	40	0	-0.00	1873.39
24		420, 90	Clear	84	1195	40	0	-218.94	1257.22
25		440, 80	Good Road	83	1495	40	0	-100.71	975.62
26		450, 60	Good Road	83	1750	40	0	-81.09	1049.01
27		440, 40	Urban	82	846	40	0	-148.16	2261.73
28		530, 90	Clear	99	900	40	0	-186.09	47.59
29		560, 100	Clear	100	915	40	0	-232.83	424.48
30		500, 80	Clear	96	575	40	0	-149.57	743.24
31		480, 80	Clear	96	2350	40	0	-124.29	303.05
32		650, 100	Light Road	83	1625	40	0	-247.78	1053.60
33		690, 100	Clear	82	1620	40	0	-264.48	850.96
34		770, 90	Light Road	81	1505	40	0	-255.70	1490.89
35		800, 60	Light Road	80	1495	40	0	-248.94	1943.40
36		740, 20	Light Road	80	1720	40	0	-181.25	1807.16
37		750, 40	Light Road	81	2285	40	0	-207.37	612.58
38		610, 70	Light Road	83	1857	40	0	-149.40	884.12
39		640, 90	Light Road	83	1128	40	0	-201.30	974.10
40		770, 60	Light Road	80	1128	40	0	-222.93	983.89

REDFOR Analysis:

Unit ID	Type	Location (X,Y)	Terrain	Elevation	Strength	Morale	Group	Threat Level	Friend Level
0		120, 530	Clear	79	1364	75	0	-0.00	0.00
1		150, 490	Clear	122	846	75	0	-746.09	625.71
2		160, 450	Clear	104	1350	75	0	-911.84	581.10
3		190, 430	Forest	82	450	75	0	-0.00	319.32
4		210, 410	Forest	117	350	75	0	-1159.24	385.35
5		230, 390	Forest	125	425	75	0	-1274.39	432.82
6		260, 380	Forest	125	525	75	0	-1220.89	411.58
7		250, 400	Forest	106	1410	75	0	-0.00	502.11
8		290, 380	Clear	112	1064	75	0	-330.32	1882.57
9		300, 360	Forest	100	1944	75	0	-428.24	843.10
10		300, 340	Good Road	86	1552	75	0	-463.05	1483.39
11		310, 310	Clear	86	1111	75	0	-609.27	1878.98
12		330, 260	Clear	98	888	75	0	-681.96	1262.29
13		320, 330	Clear	86	1410	75	0	-912.04	1315.63
14		350, 420	Clear	98	1125	75	0	-252.32	914.29
15		380, 400	Clear	88	1110	75	0	-252.66	996.53
16		390, 430	Light Road	101	1250	75	0	-360.92	2044.03
17		420, 420	Light Road	125	1100	75	0	-611.04	625.26
18		380, 420	Clear	104	1410	75	0	-356.88	459.70
19		420, 350	Clear	89	539	75	0	-538.82	393.96
20		450, 340	Clear	89	673	75	0	-701.23	492.23
21		410, 330	Good Road	89	673	75	0	-661.55	581.00
22		490, 340	Good Road	122	525	75	0	-687.31	777.19
23		410, 230	Light Road	87	502	75	0	-90.64	568.30
24		480, 220	Light Road	125	510	75	0	-575.66	926.20

Figure 16 continued.

25		450, 250	Clear	102	1128	75	0	-362.45	737.55
26		560, 220	Clear	105	500	75	0	-876.46	574.15
27		620, 250	Light Road	87	375	75	0	-670.95	102.74
28		670, 200	Light Road	85	625	75	0	-1101.21	105.63
29		730, 190	Clear	83	650	75	0	-1003.69	179.87
30		710, 230	Clear	99	282	75	0	-1024.29	189.70
31		800, 200	Clear	82	600	75	0	-879.14	245.20
32		810, 250	Clear	82	794	75	0	-731.84	209.12

Predicate Generation:

ID	Predicate Statement
0	BLUEFOR consists of 1 group.
1	Weighted strength of BLUEFOR Group 0 is: 55862.
2	The elevation at the center of BLUEFOR Group 0 is: 98.
3	The weighted elevation metric for BLUEFOR is: 133345.
4	REDFOR consists of 1 group.
5	Weighted strength of REDFOR Group 0 is: 29060.
6	The elevation at the center of REDFOR Group 0 is: 88.
7	The weighted elevation metric for REDFOR is: 89229.
8	The enemy group that can be reached quickest by BLUEFOR Group 0 is REDFOR Group 0.
9	REDFOR Group 0's frontage is an unbroken line of overlapping ROIs.
10	40 of 40 BLUEFOR units crossed an ROI to reach the Flanking Goal.
11	REDFOR'S flanks are anchored.
12	The Interior Line Value is -69051. (REDFOR has interior lines)
13	The Anchored Line Value is 100.00.
14	There is 1 choke point on the REDFOR avenue of retreat.
15	REDFOR's avenue of retreat is severely restricted.
16	There are 8 choke points on BLUEFOR's avenue of attack.
17	Unweighted BLUEFOR strength = 42120.
18	Unweighted REDFOR strength = 20658.
19	The weighted ratio of REDFOR / BLUEFOR = 0.520211.
20	BLUEFOR has the superior force.
21	The weighted elevation ratio of REDFOR / BLUEFOR = 0.669159.
22	The slope of the attack is = 1.058824.
23	BLUEFOR is attacking uphill.

Figure 16 continued.

CHAPTER IV: ALGORITHMS

During the course of this research we have implemented a number of algorithms for tactical situations within the TIGER framework. Generally speaking, the algorithms fall into two basic categories: "building block" algorithms and "special purpose" algorithms.

Building block algorithms are used by other algorithms, including both the special purpose algorithms presented here as well as other algorithms, presented elsewhere, that implement specific tactical maneuvers in the TIGER framework (Sidran and Segre 2007) and will not be presented again in this thesis. The building block algorithms are:

1. RangeOfInfluence (§ 4.1). This algorithm calculates the projection of a given unit's strength onto map coordinates.
2. ComputeGroupsByThreshold (§ 4.2). This algorithm partitions a set of military units into an appropriate number of groups based on a prespecified thresholding function.
3. ComputeGroupsByNumber (§ 4.3). This algorithm partitions a set of military units into a prespecified number of groups, while trying to conserve group cohesiveness.
4. FindPath (§ 4.4). This algorithm calculates the least-weighted path from a given unit to a prespecified goal destination according to a prespecified distance function.

Special purpose algorithms are used to compute values that can be used to classify tactical situations. Like the algorithms used to implement tactical

maneuvers (Sidran & Segre 2007), these algorithms make use of the building block algorithms of Sections 4.1 through 4.4. The special purpose algorithms are:

1. FlankingAttributeValue (§ 4.5). This algorithm returns a value that reflects the "anchordness" of a military force within a given tactical situation.
2. InteriorLinesValue (§ 4.6). This algorithm returns a value that reflects the presence or absence of interior/exterior lines of communications within a tactical situation.
3. AvenuesOfRetreatValue (§ 4.7). This algorithm returns a value that reflects the physical ability of a military force to retreat to a prespecified location within a given tactical situation.
4. AvenuesOfAttackValue (§ 4.8). This algorithm returns a value that reflects the physical ability of a military force to attack an opposing military force within a given tactical situation.

Building Block Algorithms

The ‘building block’ algorithms comprise a suite of functions that are called by other algorithms that perform tactical analysis. These basic algorithms include such functions as a least weighted path algorithm that considers enemy range of influence (described below), algorithms for finding flanks of military formations, separation of tactical positions into cohesive and self-supporting formations, the detection of breaks in frontages, etc.

Range of Influence (§4.1)

The concept of a unit’s Range of Influence (ROI) is an extension of the hexagonal board wargame Zone of Control (Dunnigan) and Influence Mapping. (Tozour), (P. Sweetser) Our implementation of ROI in TIGER allows for each

unit type in a simulation to have a unique value which represents the percentage of a unit's strength 'projected' a linear distance from the unit (see Figure 17) to a predefined distance. The ROI for each unit type is stored as an array that also includes a binary value for indicating if a unit's ROI is influenced by a blocked Line of Sight (LOS) to the target node or not.

The most obvious implementation of ROI would be a monotonically decreasing series of numbers indicating that the unit's ROI diminishes as the distance from the unit increases (see Red Group 2, Figure 17). However, our system also allows for representation of other ROIs such as concentric circles (possibly representing a unit with mixed arms, Red Group 1, Figure 17) and a unit with limited offensive power but long range observation abilities (Red Group 0, Figure 17).

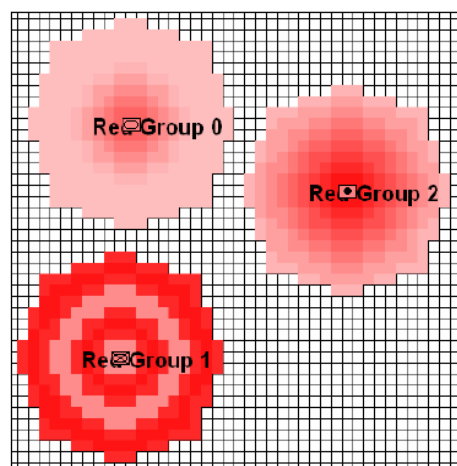


Figure 17: Examples of Range of Influence (ROI).
(TIGER screen capture.)

Groups and Lines

The ability to separate military units into logical groups is a prerequisite for any computational tactical analysis. Various methods have been employed to perform this task.

The earliest known formal description of methods for calculating groups or lines within a ‘computer wargame’ environment is Crawford’s description of his ‘Geometric AI’ used in the commercial wargame “Patton versus Rommel” circa 1988. (Crawford) Penner and Steinmetz’s JointAdvisor (2000) employed a method of drawing polygons of different colors representing the probability of accuracy upon a map in response to the query, “Where is the main defense?” (Penner and Steinmetz) Grouping is also performed by SORTS, a Real Time Strategy bot created by Wintermute, Xu and Laird. Though we employ a different grouping algorithm (SORTS uses the principle of Gestalt grouping and sorts by unit type within a predefined radius) we are, however, in agreement with their statement that groups provide a “key abstraction for tactical reasoning.” (Wintermute, Xu and Laird) Our grouping is based on an abstract notion of “proximity” which can be defined in terms of actual distance, time of traversal and/or other measures.

From a procedural perspective we employ Kruskal’s algorithm to create a minimum spanning tree (MST) of the forces (see Figure 18). (Kruskal) Units are divided into groups via MST clustering. (Zahn) In the following algorithms, clustering can be performed either by using a minimum threshold between groups (ComputeGroupsByThreshold) or by specifying the number of groups desired (ComputeGroupsByNumber).

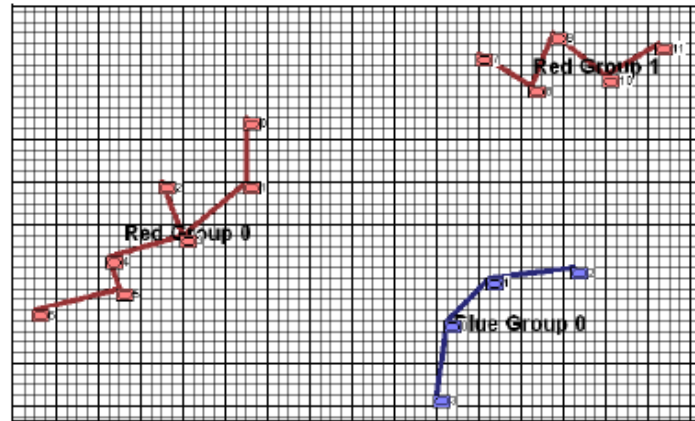


Figure 18: Grouping of units using MST clustering without terrain or elevation (TIGER screen shot).

ComputeGroupsByThreshold Function (§4.2)

The ComputeGroupsByThreshold algorithm separates a set of military units into a number of groups based on a threshold (e.g., edge weighting). In the following algorithms U is the set of all units (both opposition, OPFOR, and friendly, MYFOR). ROI values are embedded in the ‘world view’ W , which also reflects, e.g., a unit’s view of the terrain and known opposing forces.

Algorithm for ComputeGroupsByThreshold Function

// Group OPFOR units from a set U of units according to edge weighting or
 // distance function embedded in ‘world view’ W . Returns a forest of minimum
 // spanning trees corresponding to groups separated at least by distance
 // threshold D

ComputeGroupsByThreshold(U , W , D)

```
{
    // Compute MST of OPFOR units in set  $U$ 
     $T \leftarrow \text{MST}(\text{OPFOR}(U))$ 
    // Remove edges longer than distance threshold
    for  $e$  in edges ( $T$ )
        if ( $\text{weight}(e, W) > D$ )
             $T \leftarrow \text{delete}(e, T)$ 
    // Return forest of MSTs
    return( $T$ )
}
```

The threshold value can be a user-defined Euclidean distance which may be, e.g., dependent upon unit visibility as calculated by a 3D Bresenham line algorithm. (Bresenham) Other values, such as unit ROI, unit type and distance that a unit can travel over terrain within a preset period of time, can also be used to establish a threshold value.

ComputeGroupsByNumber Function (§4.3)

Though more commonly we wish to separate military units into ‘natural’ groups based upon a threshold (above), we occasionally need to separate units into a specific number of groups (e.g., when calculating the weakest point in a line).

Algorithm for ComputeGroupsByNumber Function

// Group OPFOR units from a set U of units into a fixed number of N subgroups
 // using edge weighting or distance function embedded in ‘world view’ W.
 // Returns a forest of N minimum spanning trees corresponding to groups.

ComputeGroupsByNumber (U, W, N)
 {
 // Compute MST of units in set U
 $T \leftarrow \text{MST}(\text{OPFOR}(U))$
 // Sort edges in T by length, ascending
 $E \leftarrow \text{sortAscending}(\text{edges}(T))$
 // Remove N longest edges.
 while (N > 1)
 $e \leftarrow \text{pop}(E)$
 $T \leftarrow \text{delete}(e, T)$
 $N \leftarrow N - 1$
 // Return forest of MSTs
 return(T)
 }

Computing Flanks

Another frequently used ‘building block’ is the determination of the flank units of a line. By definition the flank units are the two units that are maximally

separated (see Figure 20, below, for an example of flank units). As noted above, the edge weights may be calculated using Euclidean distance, optimal paths that hide the unit from enemy forces, etc.

There are two functions in this category: The function **CalculateLeftFlank**(U), which returns the flank unit, an element of **OPFOR**(U) and **CalculateRightFlank**(U) is analogous.

CalculateCenter Function

This function, **CalculateCenter**(U), where U is a set of units, returns the geographic center of U weighted by the Operational Lethality Index (OLI) for the unit type for each unit in U.

FindPath Function (§4.4)

FindPath is almost certainly the most ubiquitous of our functions. It is imperative that we have the ability to plot, for a specified unit, the “best” path to an assigned objective, subject to appropriate constraints and guided by a utility function based on the current world view W (which includes, e.g., enemy ROI, line of sight, etc.). Constraints are specified as a collection of barriers and forced passages that the path must avoid or traverse respectively. Thus:

FindPath(u, G, B, o, W)

where u is a unit, G a collection of “gap edges”, B a collection of “barrier edges” o is an objective, given as a location in graph coordinates and W is the unit u’s world view. **FindPath** returns the lowest cost path for unit u to objective o that intersects at least one line segment in set G and no line segments in set B, subject to an evaluation function that respects the world view expressed in W. Elements of G and B may be either edges (i.e., line segments defined between two graph

coordinates) or rays (i.e., lines rooted at a graph coordinate and extending to infinity along a given direction) which are used to impose restrictions on the legal solutions: A solution path produced by FindPath must traverse at least one of the edges given in G and none of the edges in B. Internally, such a function might use an A* path finding algorithm guided by a heuristic to minimize exposure and maximize concealment of the moving unit, should that be the nature of the pre-specified utility function (Hart, Nilsson and Raphael) (see also (Becker)). Finally, the function should return a measure of quality of the path constructed, so that two paths computed separately can be directly compared according to the utility function used to construct them.

In addition, we employ numerous variations of FindPath that employ various *ad hoc* edge weightings such as uniqueness of path (for choke point calculations), with, or without, either REDFOR or BLUEFOR ROIs (for flank and restricted avenues of approach and retreat calculations), etc.

Algorithms that Return Attribute Values

This group of algorithms returns values that represent the value of attributes that describe tactical situations (see Chapter 2) and are crucial to the CLASSIT clustering system. In all cases they employ ‘building block’ algorithms described above.

FlankingAttributeValue Function (§ 4.5)

This function determines if REDFOR (the defending military formation) possesses the quality of ‘anchored flanks’ and returns value that accurately reflects ‘anchoredness’ of its line.

As discussed above, the flanks of a line (or the flanking units of a line) are defined as the two maximally separated units in the MST defining a group of units. A prerequisite for a line with anchored flanks (or an anchored line) is that there must not be any ‘holes’ in the line; that is to say, that an anchored line must consist of a series of supporting units that have overlapping ROI, or fields of fire. (Sidran and Segre) Therefore, an attacking (BLUEFOR) unit cannot navigate a path from its current position to an appropriately selected point behind an anchored line without crossing through an ROI of a different color.

In informal terms our algorithm for determining the presence of anchored flanks is as follows. First, determine the ‘spine’ of the MST group (see Figure 20) which is the unique path on the edges of the MST from one flank unit to the other flank unit. Second, determine if the spine traverses an uninterrupted line of ROIs that reach from one flank unit to the opposite flank unit. Next, locate an objective point that places the spine between the objective point and BLUEFOR units (see Figure 21). If a legal path can be traced from any BLUEFOR unit to the objective point without passing through an ROI then at least one flank is unanchored. If no legal path can be found from any BLUEFOR unit to the objective point without passing through an ROI then both flanks are anchored.

The ratio of the number of BLUEFOR units that had to cross through a REDFOR ROI over the total number of BLUEFOR units serves as a measure for the ‘flanking attribute’ employed by our classification system where larger values imply REDFOR’s flanks are more secure. In addition to this ‘flanking attribute’ metric this algorithm also produces several additional useful attributes, in particular, whether the REDFOR line consists of an unbroken chain of ROI,

whether BLUEFOR units must cross REDFOR ROI to reach the selected flanking objective point, and a ratio of compromised to uncompromised BLUEFOR units.

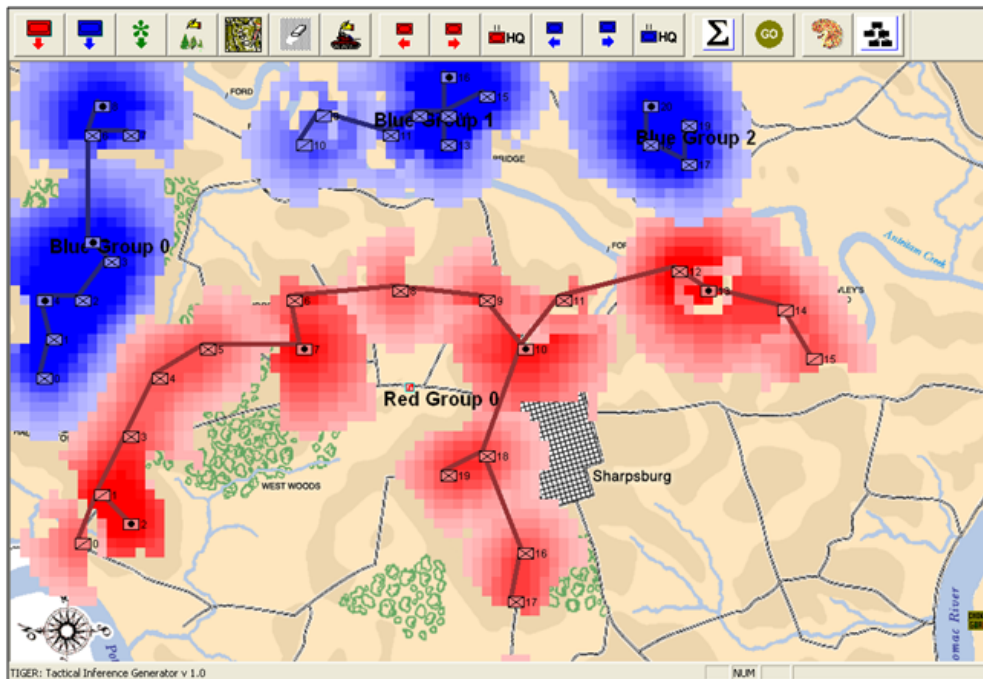


Figure 19: The battle of Antietam which REDFOR ROIs, BLUEFOR ROIs and MSTs displayed (TIGER screen shot).

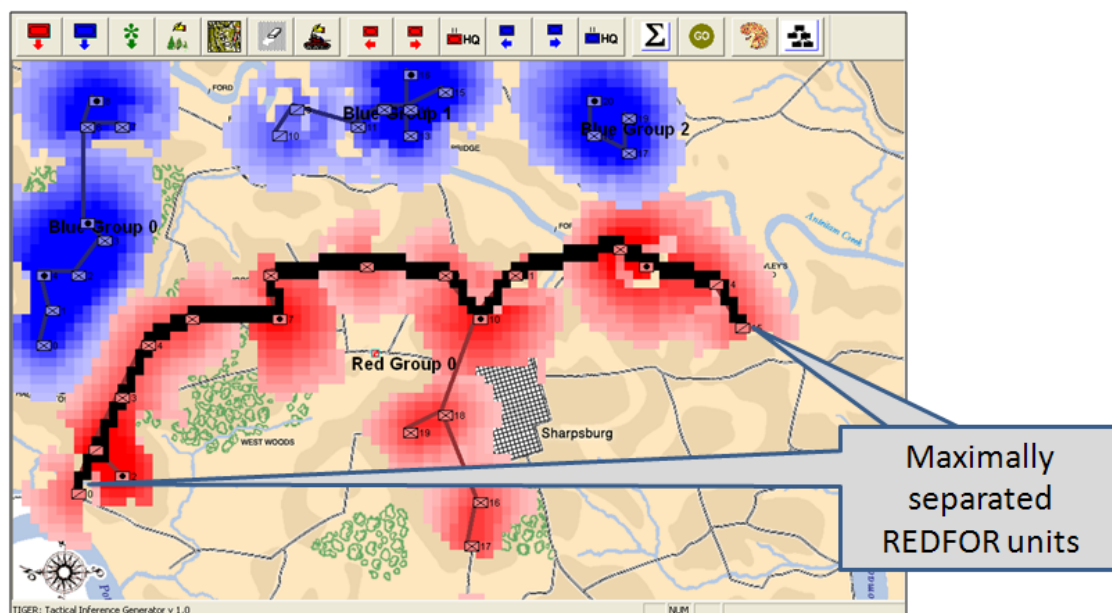


Figure 20: The MST spine displayed as a thick black line and the two REDFOR flank units indicated by arrows (TIGER screen shot).

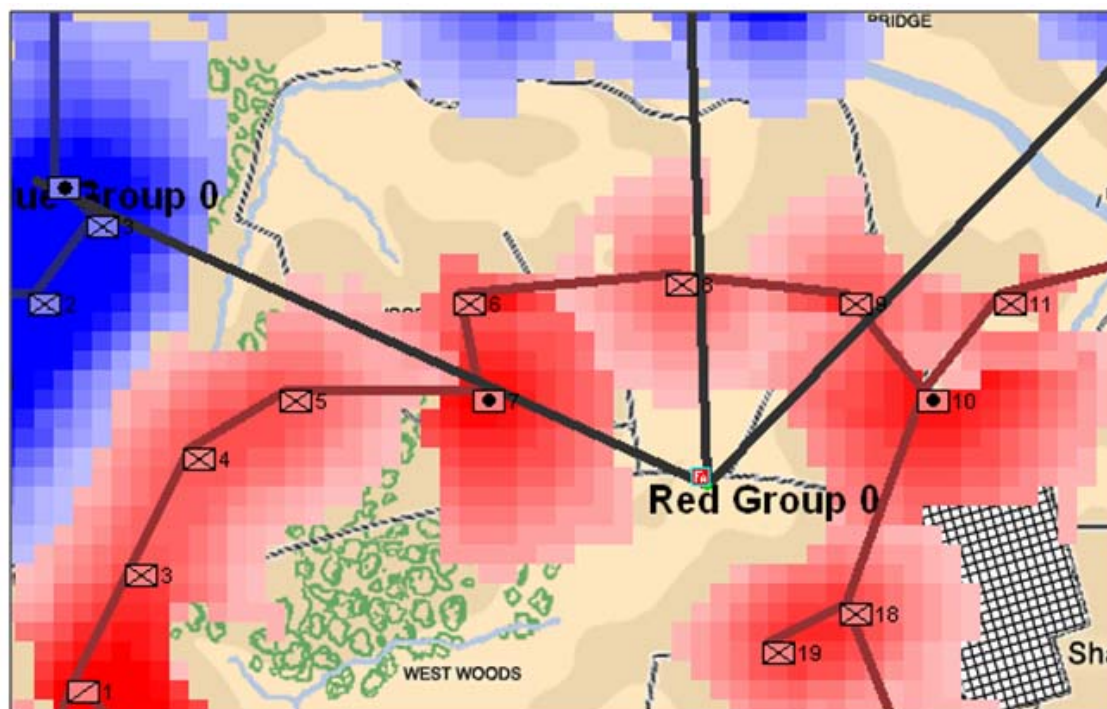


Figure 21: Location of Flanking Goal Objective Point (TIGER screen shot).

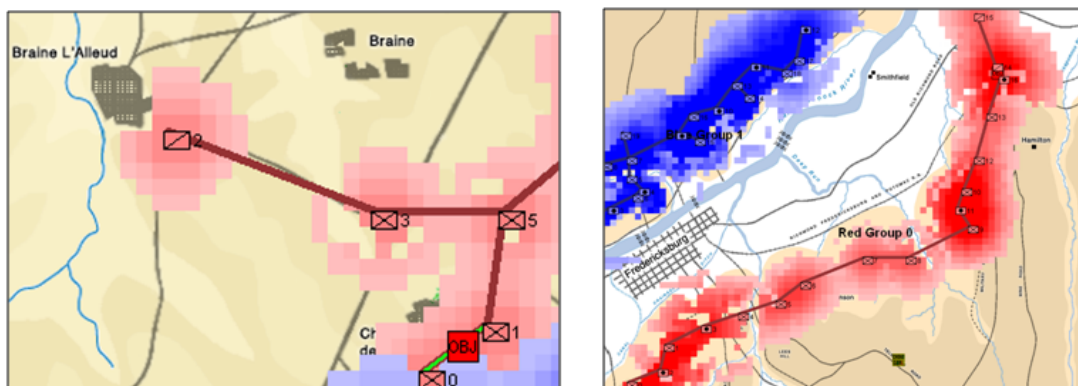


Figure 22: Interrupted line of ROIs (left), uninterrupted line of ROIs (right)
TIGER screen shots.

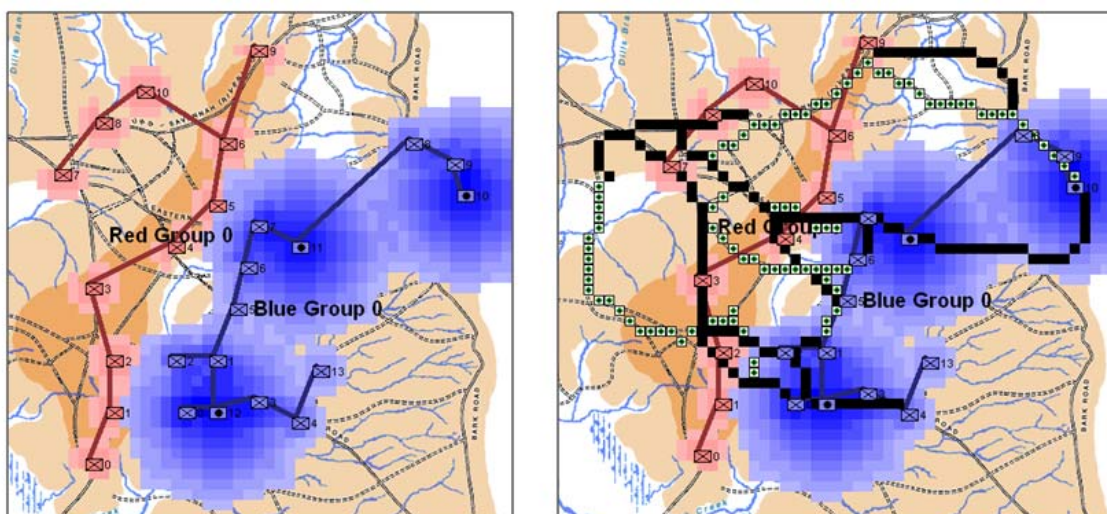


Figure 23: Example of how FindPath avoids REDFOR ROI (right) as it traces a legal path from each unit to the objective point.

Algorithm for FlankingAttributeValue Function

// Determine if R, a set of REDFOR units, has anchored flanks given B, a set of
 // BLUEFOR units. D is a distance threshold. W is the 'world view' used by
 // FindPath. Matrices that represent terrain and elevation maps are global. Returns
 // V, a real-valued attribute suitable for use within the ClassIT system.

FlankingAttributeValue (R, B, D, W)

```
{
    // Calculate the MSTs for REDFOR and BLUEFOR
    B_MST ← ComputeGroupsByThreshold(B,W,D)
    R_MST ← ComputeGroupsByNumber (R, 1)

    // Calculate ROI for REDFOR
    R_ROI ← CalculateROI(R)

    // Find left and right flanks of REDFOR
    l ← CalculateLeftFlank(R)

    // Determine MST spine of R
    R_Spine ← PlotMSTspine(R, l, r)

    // Determine the center of REDFOR
    R_Center ← CalculateCenter(R)

    // Keep a count of how many BLUEFOR units have a legal path free of
    // R_ROI to their respective objectives; initialize counter
    N ← 0

    // For each BLUEFOR group, represented by an MST in the forest of
    // BLUE MSTs
    for each BGm in B_MST

        // Calculate center of this BLUEFOR group
        B_Center ← CalculateCenter(BGm)

        // Find first REDFOR ROI-free objective beyond the MST spine of
        // R (R_Spine) along the ray from B_Center to R_Center
        o ← FindOpenPoint(B_Center, R_Center, R_Spine, R_ROI)

        // For each unit in this group see if a legal path exists to the
        // objective point o
        for each u in BGm
            if (FindPath(u,∅,R_ROI,o,W))
```

$$N \leftarrow N + 1$$

```

// Return the ratio of the number of BLUEFOR units with R_ROI clear
// paths to their respective objectives to the total number of BLUEFOR
// units
return (N / |B| )
}

```

InteriorLinesValue Function (§ 4.6)

This function determines if REDFOR (the defending military formation), or BLUEFOR (the attacking military formation) possesses the quality of ‘interior lines’ (as defined in Chapter 1, above) and returns a real-valued number that accurately reflects the advantage of the respective formations. The values range from negative (REDFOR has interior lines) to positive (BLUEFOR has interior lines); the greater the absolute value, the greater the advantage.

In informal terms our algorithm for determining the presence of interior lines is as follows: First, find the left and right flank units for REDFOR and BLUEFOR groups. Next, find the least weighted path between the flank units of each group using FindPath (checking in both directions because the costs are not symmetrical due to different unit types, terrains, slopes, etc.). Last, subtract the smallest cost (returned by FindPath) for BLUEFOR from the smallest cost (returned by FindPath) for REDFOR.

Algorithm for InteriorLinesValue Function

```

// Determine if R, a set of REDFOR units, or B, a set of BLUEFOR units, has the
// attribute of interior lines and return a real-valued attribute suitable for use
// within the ClassIT system. W is the ‘world view’ used by FindPath.

```

InteriorLinesValue (B, R, W)

```

{
    // Find left and right flanks of REDFOR
    l ← CalculateLeftFlank(R)
    r ← CalculateRightFlank(R)

```

```

// Calculate ROI for BLUEFOR
B_ROI  $\leftarrow$  CalculateROI(B)

// Find the path with the least cost between l and r (check both directions),
// store in B_Path
B_Path  $\leftarrow$  Min ( FindPath (l,  $\emptyset$ , R_ROI, r, W), FindPath (r,  $\emptyset$ , R_ROI,
l, W))

// Find left and right flanks of BLUEFOR
l  $\leftarrow$  CalculateLeftFlank(B)
r  $\leftarrow$  CalculateRightFlank(B)

// Calculate ROI for REDFOR
R_ROI  $\leftarrow$  CalculateROI(B)

// Find the path with the least cost between l and r (check both directions),
// store in R_PATH
R_Path  $\leftarrow$  Min( FindPath (l,  $\emptyset$ , B_ROI, r, W), FindPath (r,  $\emptyset$ , B_ROI,
l, W))

// Subtract the minimum REDFOR path from the minimum BLUEFOR
// path and return the Interior Line metric
return(B_Path - R_Path)

```

}

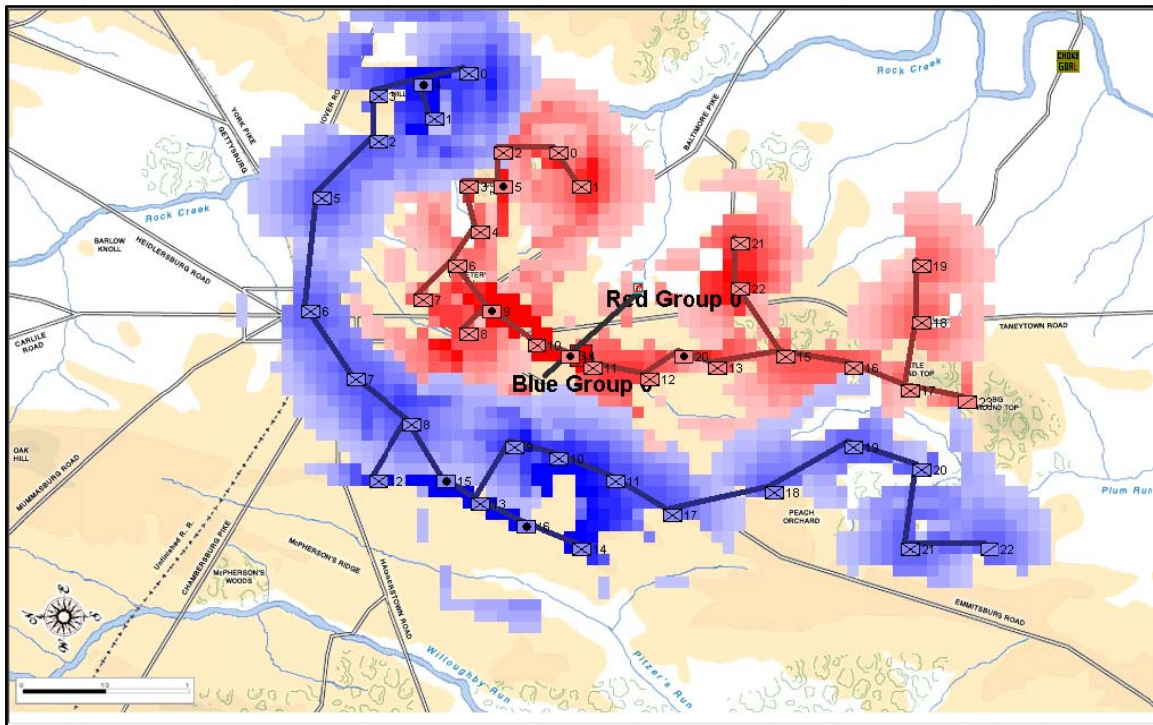


Figure 24: An example of REDFOR possessing the attribute of ‘Interior Lines’; i.e., the weight of the edge between the REDFOR flank vertices is less than the weight of the edge between the BLUEFOR flank vertices. Note how ROI effects the edge weight. (TIGER screen shot.)

RestrictedAvenuesOfRetreatValue Function (§ 4.7)

This function determines the number of ‘choke points’ between REDFOR (the defending formation) and a predetermined retreat goal and returns a real-valued number suitable for use for instance classification.

The point (C) that REDFOR wishes to retreat to requires *a priori* knowledge of the strategic situation which is beyond the scope of the tactical ‘snapshot’ that is presented to TIGER for analysis. Consequently, C, is set by an SME (see Figure 25 for an example where C has been set as a point on the southern bank of the Potomac River that the Confederate army must pass through during a retreat to its strategic base in Virginia).

In informal terms our algorithm for determining the presence of Restricted Avenues of Retreat for REDFOR is as follows: an SME, using TIGER, sets the REDFOR Retreat Choke Point Goal (C) and TIGER calculates the BLUEFOR ROI. Next, for each group in REDFOR, or until FindPath returns failure, find a path from the center of the group to C that is completely disjoint from previous REDFOR retreat paths. The value returned, the REDFOR Chokepoint Value (RC), corresponds roughly to a notion of “bandwidth” to a single objective, the Choke Point Goal. Since we are operating on a map with an overlaid square grid, the number of disjoint access paths to a single objective point is an integer between 0 and 8, inclusive. Thus the RC, defined as:

$$RC = \frac{1}{2^{(\text{NumberChokePoints} - 1)}}$$

is a number in the range [0.007813,1.0], where a smaller number means REDFOR has more avenues of retreat, and a value of 1.0 means REDFOR has only a single avenue of retreat (see Figure 25, below, for an example of RC = 1.0).

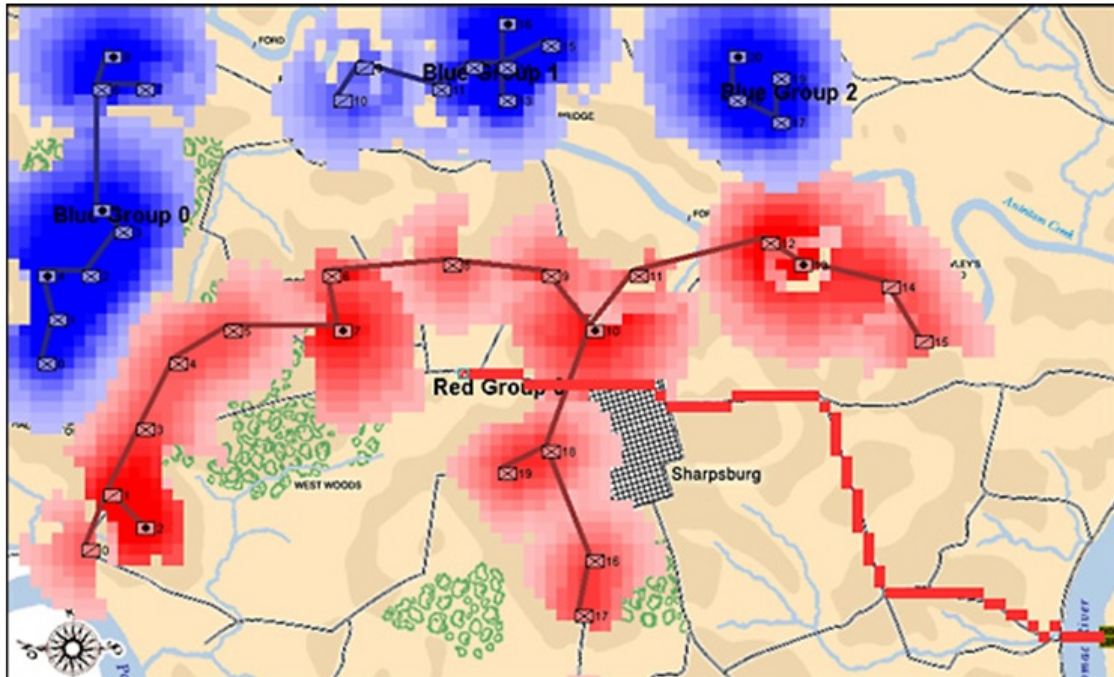


Figure 25: An example of REDFOR with a severely restricted Avenue of Retreat (RC = 1.0). TIGER screen shot.

Algorithm for AvenuesOfRetreatValue Function

// Given R, a set of REDFOR units and B, a set of BLUEFOR units, calculate the
 // number of choke points between R and the Choke Point Goal (C) and return a
 // value suitable for use within the ClassIT system. W is the 'world view used by
 // FindPath. D is a distance threshold.

AvenuesOfRetreatValue (B, R, C, W, D)

{

 // BARRIER is initialized to hold BLUEFOR ROI

 BARRIER $\leftarrow$ CalculateROI(B)

 // Initialize N, the NumberofChokePoints

 N $\leftarrow$ 0

 // Calculate the MSTs for REDFOR

 R_MST $\leftarrow$ ComputeGroupsByThreshold(R, W, D)

 // For each REDFOR group, represented by an MST in the forest of

 // REDFOR MSTs

for each RG_m in R_MST


```

// Calculate center of this REDFOR group
R_Center  $\leftarrow$  CalculateCenter(RGm)

while(P  $\leftarrow$  FindPath(R_Center,  $\emptyset$ , BARRIER, C, W))
    N  $\leftarrow$  N+1
BARRIER  $\leftarrow$  BARRIER  $\cup$  P

// Return the REDFOR Chokepoint Value
return(1 / Power (2,N-1))
}

```

RestrictedAvenuesOfAttackValue Function (§ 4.8)

Restricted Avenues of Attack for BLUEFOR is identical to the algorithm for determining the presence of Restricted Avenues of Retreat (above) except that FindPath is called without using enemy ROI and that the Choke Point Goal (C) is not set by an SME but rather C is set as the center of REDFOR. Like Restricted AvenuesOfRetreatValue (above), a smaller number means BLUEFOR has more avenues of attack, and a value of 1.0 means BLUEFOR has only a single avenue of attack.

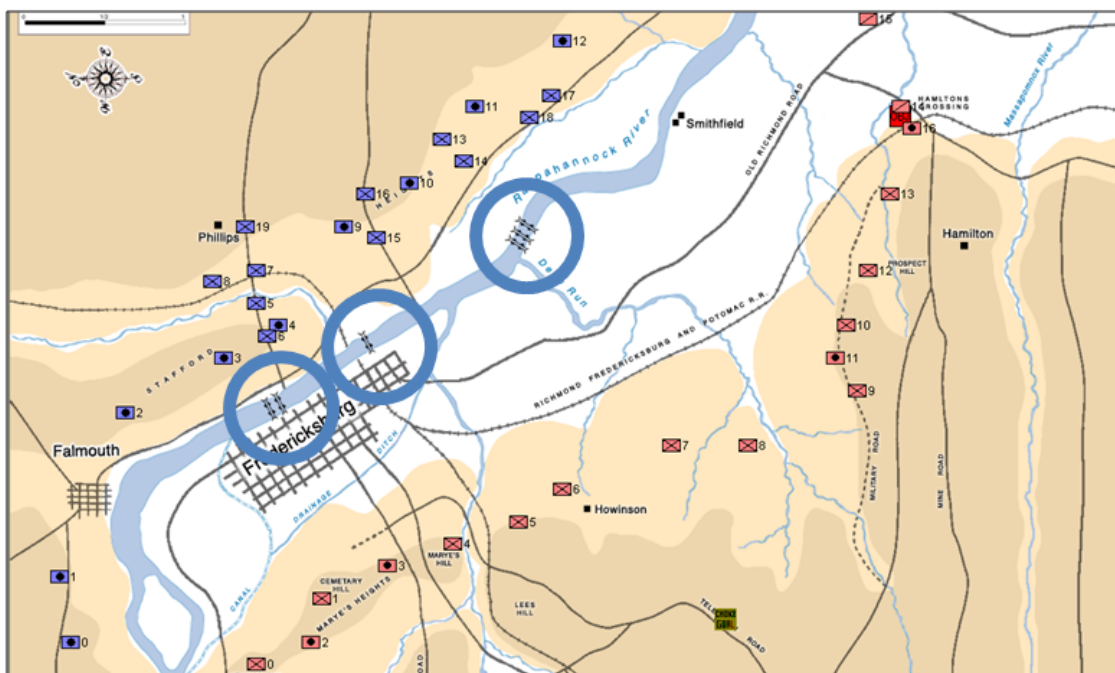


Figure 26: The situation at the battle of Fredericksburg in which BLUEFOR must cross three sets of pontoon bridges to attack REDFOR (TIGER screen capture).

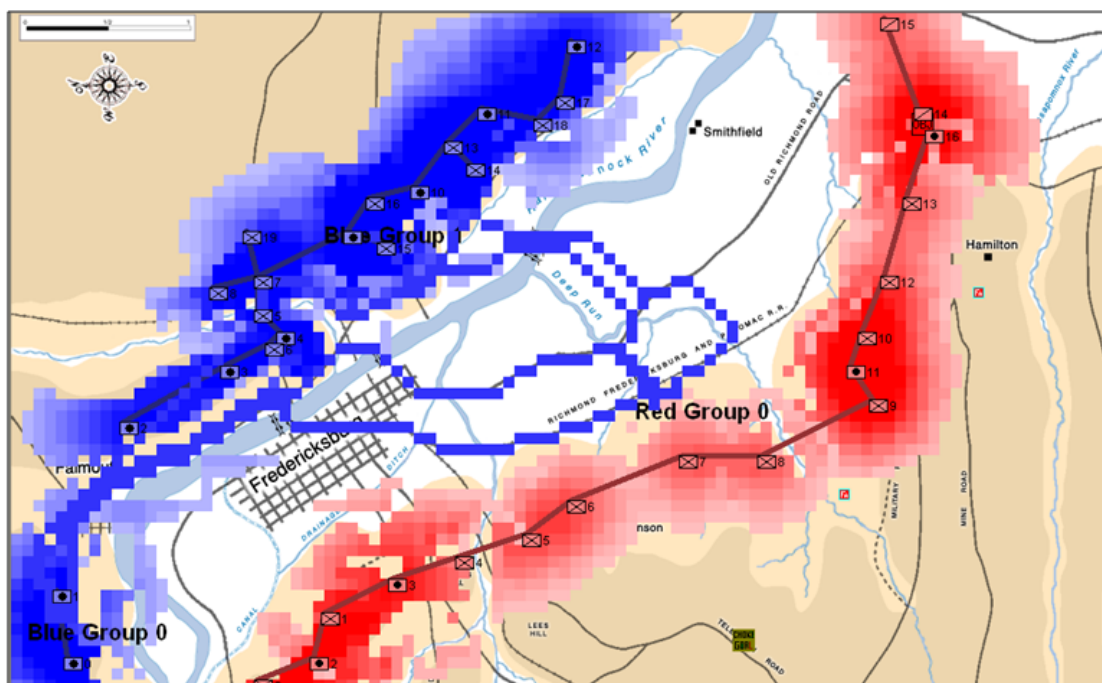


Figure 27: TIGER's display of discovered Choke Points and Restricted Avenues of Attack (TIGER screen capture).

Algorithm for AvenuesOfAttackValue Function

// Given R, a set of REDFOR units and B, a set of BLUEFOR units, calculate the
 // number of choke points between B and the Choke Point Goal (C) and return a
 // value suitable for use within the ClassIT system. W is the ‘world view’ used by
 // FindPath. D is a distance threshold.

AvenuesOfAttackValue (B, R, C, W, D)

```
{
    // Determine the center of REDFOR
    R_Center  $\leftarrow$  CalculateCenter(R)

    // Initialize N, the NumberofChokePoints
    N  $\leftarrow$  0

    // BARRIER is initialized empty
    BARRIER  $\leftarrow$   $\emptyset$ 

    // Calculate the MSTs for BLUEFOR
    B_MST  $\leftarrow$  ComputeGroupsByThreshold(B,W, D)

    // For each BLUEFOR group, represented by an MST in the forest of
    // BLUEFOR MSTs
    for each BGm in B_MST

        // Calculate center of this BLUEFOR group
        B_Center  $\leftarrow$  CalculateCenter(BGm)

        while(P  $\leftarrow$  FindPath(B_Center,  $\emptyset$ ,BARRIER, R_Center,W))
            N  $\leftarrow$  N+1

        BARRIER  $\leftarrow$  BARRIER  $\cup$  P

    // Return the BLUEFOR Chokepoint Value
    return (1 / Power (2,N-1))
}
```

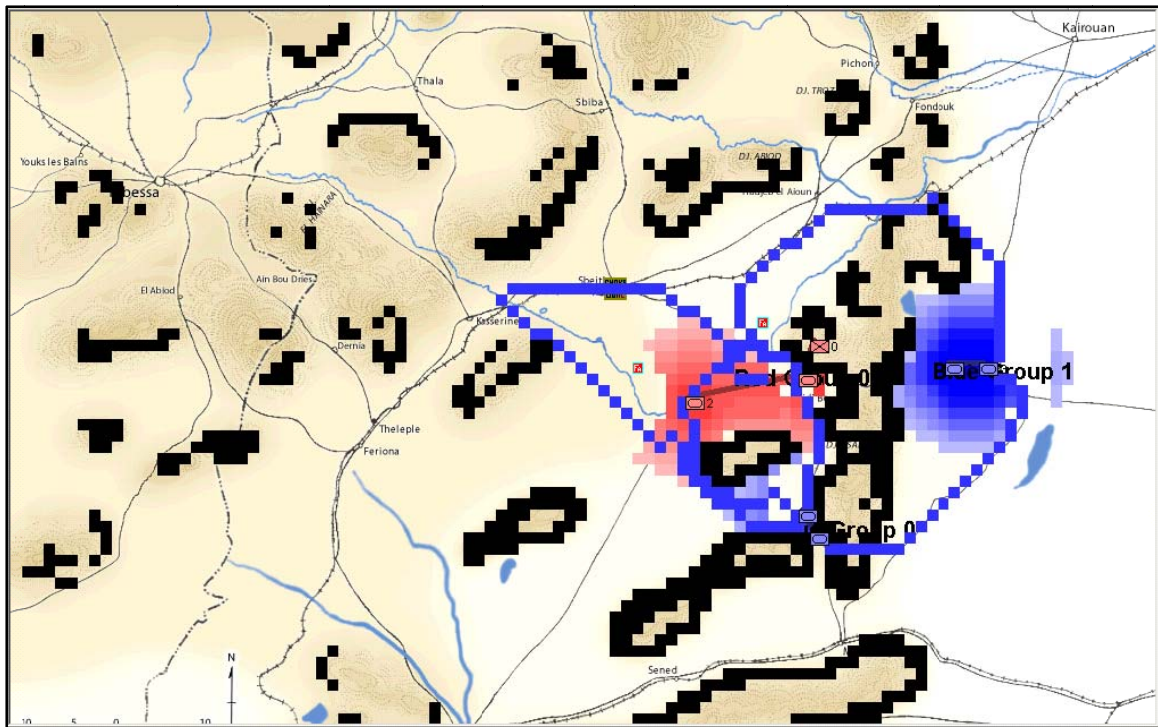


Figure 28: Example of BLUEFOR (Axis) having Restricted Avenues of Attack (marked by thick blue lines) at the battle of Kasserine Pass, February 14, 1943). Note that the black areas have greater slopes than the unit type (armor in this case) allows for transit. Also, note that the slope restrictions are calculated as part of the FindPath function and, consequently are calculated only on an 'as need' basis. Mountain ranges to the west were not considered by the function and, therefore, their slopes are not marked as impassable. (TIGER screen capture.)

CHAPTER V: SURVEYS AND VALIDATION

As noted in Figure 1, above, Subject Matter Experts (SMEs) were involved throughout this research: identifying important attributes for classification, validating the values produced by the algorithms and validating the final classification output. Our list of SMEs drew heavily from active duty field grade officers of the U. S. Army as well as tactical instructors from the U. S. and foreign Canadian, Australian and British) militaries. The surveys were conducted using the University of Iowa WebSurveyor system and with IRB approval.

Survey 1

The purpose of the first survey that we conducted (see Appendix A) was, “to determine if there is a common agreement among subject matter experts of the validity of attributes that can be used to separate tactical situations into meaningful categories.” Because we were interested in tactical situations in which opposing forces had ‘room to maneuver’, most of the tactical situations were drawn from the Napoleonic and American Civil Wars (though we were able to include Kasserine Pass from World War II, which also met our conditions).

We surveyed 14 SMEs on the presence (or absence) of 4 specific attributes (anchored or unanchored flanks, restricted avenues of attack, restricted avenues of approach and interior lines) in 16 tactical situations. We chose the specific tactical situations because we felt that they were representational examples of the presence (or absence) of the key attributes that we wished to validate. The results, in table form, appear below. The complete tabulated responses from Survey 1

appear in Appendix A, along with individual free-form comments from respondents.

Table 2 Survey #1 Results

Tactical Situation:	Key Attribute:	% Agreement:
Antietam	RED Left Flank Anchored	100%
Antietam	RED Right Flank Anchored	79%
Chancellorsville	BLUE Left Flank Unanchored	71%
Chancellorsville	BLUE Right Flank Anchored	93%
Waterloo	BLUE Left Flank Unanchored	92%
Waterloo	BLUE Right Flank Unanchored	71%
Austerlitz	RED Right Flank Unanchored	100%
Austerlitz	RED Left Flank Unanchored	86%
Fredericksburg	RED Left Flank Anchored	100%
Chattanooga	RED Right Flank Anchored	79%
Chancellorsville	RED has interior lines	92%
Antietam	RED has interior lines	85%
Gettysburg	BLUE has interior lines	92%
Wilderness	BLUE has interior lines	71%
Antietam	RED has restricted avenue of retreat	64%
Kasserine Pass	AXIS has restricted avenues of approach	71%
Kasserine Pass	ALLIES have restricted avenues of retreat	78%
Gettysburg	BLUE has restricted avenue of retreat	64%
Chancellorsville	BLUE has restricted avenue of retreat	71%
Fredericksburg	BLUE has restricted avenue of approach	57%
Chattanooga	RED does not have restricted avenue of retreat	71%

The results from Survey #1 confirm that there were attributes present in these tactical situations and that they could be identified with a high degree of

certainty. However, it was also apparent that each of these attributes had a range of values, for example, ‘interior lines’ ranged from extremely advantageous (Gettysburg and Chancellorsville) to less pronounced (Wilderness).

These results guided our development of algorithms (see Chapter 4) and were used to validate the output of the algorithms.

Survey 2

The purpose of the second survey was to determine if there was agreement among SMEs in determining the similarity or dissimilarity of historical tactical situations based on the output of TIGER’s algorithms that were created after Survey #1. In this survey the SMEs were shown six pairs of TIGER screen captures of tactical situations and asked if, in their opinion, the two tactical situations were similar or dissimilar. The first set of three tactical situations, TIGER classified as similar. The second set of tactical situations TIGER classified as dissimilar. In this survey, the SMEs had *a priori* knowledge of TIGER’s choices and were simply asked to agree or disagree with TIGER.

Table 3 Survey #2 Results

Tactical Situation ‘A’	Tactical Situation ‘B’	% Agreement with TIGER
TIGER classified as ‘similar’		
Gettysburg Day 1	Waterloo 1430 hours	91%
Fredericksburg	Waterloo 1600 hours	58%
Shiloh 0900 hours	Shiloh 1200 hours	86%
TIGER classified as ‘dissimilar’		
Antietam	Shiloh Day 2	83%
Gazala	Fredericksburg	83%
Lake Trasimene	Kasserine Pass	100%

The SME list was identical to Survey #1. The SMEs agreed with the output of TIGER's algorithms as to the similarity or dissimilarity of the tactical situations; usually by a wide margin (see Appendix B for the actual survey and SME comments).

Survey 3

The purpose of the third survey was to test *Hypothesis 2*: The best match (by TIGER of a new scenario to a scenario from its historical database) predicts what the experts would choose. In this survey our original list of SMEs was augmented by seven active duty field grade officers of the U. S. Army; making a total of 23 SMEs.

This survey consisted of five sets of hypothetical tactical situations paired with a historical situation that TIGER placed within the same cluster, and a historical situation that TIGER placed in a disjoint cluster (see Appendix D). The SMEs were then asked if they felt that the hypothetical situation was more like historical situation 'A', historical situation 'B' or 'neither'. The SMEs had no *a priori* knowledge of TIGER's 'prediction'.

Table 4 Survey #3 Results

Situation 'A'	Situation 'B'	SME Choice (%) A/B/Neither	TIGER's prediction	% Agreement
Waterloo	Antietam	65.2 / 26.1 / 8.7	B	26.1%
Kasserine Pass	Gettysburg	91.3 / 4.3 / 4.3	A	91.3%
Gettysburg Day 2	Shiloh	73.8 / 26.1 / 0.0	A	73.9%
Gettysburg Day 3	Fredericksburg	0.0 / 100.0 / 0.0	B	100.0%
Shiloh 0900	Chancellorsville	69.6 / 13.0 / 17.4	A	69.6%

TIGER correctly predicted the SME's choice in four out of five tests (80%).

A one-sided Wald test was used to test $H_0: \beta=0$ (i.e. $P(\text{Match}) = 0.5$) vs. $H_1: \beta > 0$ (i.e. $P(\text{Match}) > 0.5$) and resulted in $p < 0.0001$ which is statistically significant. This was calculated using the marginal logistic regression model, odds $(\text{Match}) = \exp(\beta)$, that accommodates within expert correlated observations was fitted using estimating equations (see (Liang and Zeger)). That is, the test statistic of the form $W = \hat{\beta} / \text{ase}(\hat{\beta})$ was compared to 0.⁷ Specifically, the p-value was computed as $p = P(N(0,1) \geq \hat{\beta}/\text{ase}(\hat{\beta}))$

A table of Clopper-Pearson 95% confidence intervals appears below:

⁷ ase = Asymptotic Standard Error.

Table 5 Clopper-Pearson 95% confidence intervals for Survey #3

Test #	% Agreement:	Lower and Upper Bounds:
1	0.261	[0.102, 0.484]
2	0.913	[0.720, 0.989]
3	0.739	[0.516, 0.898]
4	1.000	[0.852, 1.000]
5	0.696	[0.471, 0.868]

We conclude that these results validate hypothesis 2 and are statistically significant.

CHAPTER VI: CONCLUSIONS AND FUTURE RESEARCH

Conclusions

The results of all three surveys show consistent responses from SMEs indicating agreement that certain features exist that can be used by SMEs to group tactical situations by similarity. We therefore conclude that the first hypothesis has been validated. Furthermore, we have established a set of these features (see Chapter 1), confirmed by SME survey and a series of algorithms (see Chapter 4) that produce a range of appropriate values for these attributes, that can be used by CLASSIT for classification based on similarity.

Our final survey has demonstrated, within a 95% confidence interval, that TIGER using these attribute values and employing an unsupervised machine learning clustering system, will produce a best match of a new scenario to a scenario from its historical database that predicts what the experts would choose 80% of the time. We therefore conclude that the second hypothesis has been validated.

A Question and a New Hypothesis

The surveys that we have conducted indicate the TIGER possesses the ability to predict what the SMEs would choose the vast majority of the time. Indeed, within the narrowly defined area of ‘tactical military expertise’ one could state that TIGER passes the infamous ‘Turing Test’ with statistical room to spare. If we were to imagine the Turing Test conducted, and restricted to the area of ‘tactical military expertise’, with TIGER behind one door and a general behind the other and all interactions restricted to the input and output of military units on

a topographical map, a human ‘interrogator’ would surely have a difficult time differentiating between TIGER and the human.

However, we are left with an interesting question, “Why does TIGER not agree with the SMEs 100% of the time?” In the third survey TIGER disagreed with the SMEs in only one test. Why?

Preliminary analysis of this discrepancy (Antietam, survey #3, question #1) shows that TIGER analyzed and clustered these the specific tactical situation as expected. It may well be the case that the SMEs missed the subtleties of the tactical situation that TIGER saw (or that TIGER missed something that the SMEs saw).

Future Research

If T is the set of TIGER’s ‘solutions’ to tactical situations and S is the set of SME solutions to the same tactical situations, we suggest that the area of $T-S$ might be an extraordinarily interesting area of research. That is to say, that the area where SMEs and TIGER agree, while it has been an area of gratifying research for the author, may not be as important as the area of disagreement.

Consider this statement from “Wired for War” which explores the future of robotic and AI in future warfighting, “Because searching through data and then processing it takes too much time, human commanders without such aids [i.e., an ‘expert system’ software such as RAID8] have to pick out which data they want to look at and which to ignore. Not only does this inevitably lead them to skip the

8 RAID (Real-time Adversarial Intelligence & Decision-making) is a DARPA sponsored-project three-year program begun in 2004 mentioned by Singer in the paragraph immediately preceding this quote. Its design specifications require the ability to ‘look ahead into the future’ by ‘at least 5 hours’ and to calculate enemy intentions within 30 seconds. The RAID PowerPoint briefing is available here: <http://www.darpa.mil/IPTO/programs/raid/docs/RAID.ppt>

rest of the information that they don't have time to cover, but *humans also tend to give more weight in their decisions to the information they see first, even if it not representative of the whole. The result is 'satisficing'*⁹ They tend to come up with a satisfactory answer, though not the optimal answer." (Emphasis added)

(Singer) It is indeed possible that either TIGER or the SMEs chose a satisfactory, rather than an optimal, answer to test question 1 in the third survey.

Final Statement

This research, which was originally conceived as the capstone of years of work on the subject has, instead, generated more questions that will require more research.

Nonetheless, we take great pride in presenting TIGER. It is a unique program, comprised of an original suite of algorithms that we hope will facilitate the study of computational military reasoning.

⁹ 'Satisficing' is a combination of the words of "satisfy" and "suffice", coined by psychologist Herbert Simon and used in decision making, artificial intelligence and economics to describe the situation of picking the first 'adequate' solution found rather than the optimal solution. (Wikipedia, Satisficing)

APPENDIX A: REPORT OF FIRST SURVEY OF SUBJECT MATTER EXPERTS

Overview:

The purpose of the survey is to determine if there is a common agreement among subject matter experts of the validity of attributes that can be used to separate tactical situations into meaningful categories and to suggest other attributes not presented in this survey.

The survey consisted of 16 tactical situations that were divided into categories of:

- Anchored and unanchored flanks
- Interior lines
- Restricted areas of attack
- Restricted areas of retreat

IRB Approval:

The IRB ruled this survey exempt.

Subject Matter Experts:

Fourteen Subject Matter Experts participated in the survey. They included:

- 7 Professional Wargame Designers
- Active duty and retired U. S. Army officers including:
 - Colonel (Ret.) USMC infantry 5 combat tours, 3 advisory tours
 - Maj. USA. (SE Core) Project Leader, TCM-Virtual Training
 - Officer at TRADOC (U. S. Army Training and Doctrine Command)
 - West Point; Warfighting Simulation Center
 - Instructor, Dept of Tactics Command & General Staff College
- Tactics Instructor at Kingston (Canadian equivalent of Ft. Leavenworth)

The survey, as it appeared on the web, is presented below with the survey responses for each question immediately following.



Identifying important attributes of tactical situations.

First, thank you very much for making the time in your schedule to take this survey. We know that you are busy, but your input is vital to our research.

Second, and we cannot stress this enough, you are not being tested. There are no 'right' or 'wrong' answers in this survey.

Third, you can stop this survey at any point and return later to complete the survey where you left off.

Our Research

We theorize that tactical situations can be separated into meaningful categories by the use of algorithms that calculate the values of significant attributes and classify the tactical situations accordingly.

For example, one of the 'attributes' that we have identified is the attribute of 'anchored flanks'. It is logical to assume that tactical situations in which both red and blue forces have anchored flanks are more similar than those in which neither red nor blue forces have anchored flanks.

This Survey:

The purpose of this survey is to determine if there is a common agreement among subject matter experts of the validity of attributes that can be used to separate tactical situations into meaningful categories and to suggest other attributes not presented in this survey.

This survey is conducted as part of the doctoral research by D. Ezra Sidran, Department of Computer Science at the University of Iowa. To contact the survey author with questions or comments please send email to dsidran@cs.uiowa.edu. A link to our research papers on the subject of computational military reasoning is here: [papers](#) (link opens in a new window).

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Identifying important attributes of tactical situations.

Attributes:

Our research involves identifying significant features of tactical situations so that they may be categorized. We use the term 'attributes' to describe these significant features that we will use to separate tactical situations into similar categories.

To date we have identified the following attribute candidates:

- Anchored and Unanchored Flanks
- Interior Lines
- Restricted Avenues of Attack
- Restricted Avenues of Retreat

In the following pages you will be shown a tactical situation (taken from *The West Point Atlas* series of historic battles) and asked if, in your opinion, a specific attribute is present.

On every page there is also a comment box for you to enter any comments about that particular tactical situation. In particular, we are interested in any new attributes that you, as a Subject Matter Expert, deem relevant to the particular tactical situation that is shown.

Please note: these terms are 'attribute candidates'; if you feel that the candidate is not a good, or valid, attribute please select 'N/A' from the choices in the following pages (here N/A could mean either 'not applicable' or 'not an attribute').

Also, at the end of the survey you will be asked to suggest other possible attribute candidates as well.

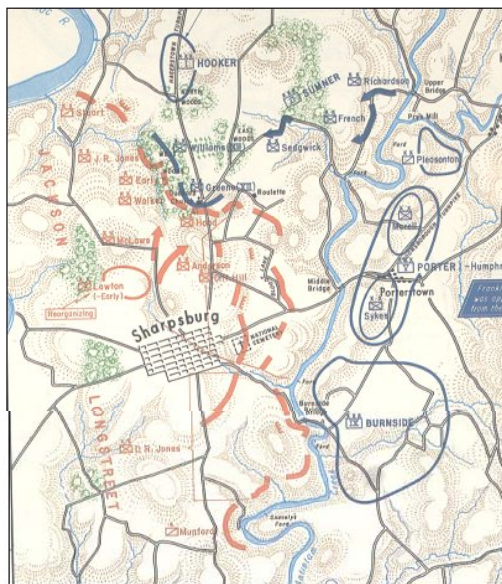
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Identifying important attributes of tactical situations.

Anchored and Unanchored Flanks



In the first series of survey questions we are interested in 'attributes' that define types of flanks and that we can use for classification of categories of tactical situations.

We are using the following definitions:

Flank - either end of a mobile or fortified military position.

Anchored Flank - (also called a *refused flank*) is attached to or protected by terrain, a body of water, or defended fortifications.

Unanchored Flank - (also called an *open flank*) a flank that is not protected. Also an unanchored flank is said to be "in the air";

Antietam situation about 0900, 17 September 1862.

[Source: *Atlas for the American Civil War*. Wayne, NJ: Avery Publishing Group, 1986; map 14a]

For this question we would like you to look at the map of the battle of Antietam. The **Confederate units** are indicated in red. The **Union units** are indicated in blue.

Stuart's cavalry is the Confederate left flank (northern flank); Munford's cavalry is the Confederate right flank (southern flank). Hooker's I Corps is the Union right flank (northern flank) and Burnside's IX Corps is the Union left flank (southern flank).

Please select one answer from each of the following. If you feel that the attribute of 'anchored flank' or 'unanchored flank' is present for a particular flank, please select the appropriate box. Select 'N/A' if you feel that

'anchored flanks' are **not** a legitimate attribute for classification of tactical situations.

	Anchored (or Refused) Flank	N/A	Unanchored (or Open) Flank
Red left (northern) flank	☒	☐	☐
Red right (southern) flank	☒	☐	☐
Blue right (northern) flank	☐	☐	☒
Blue left (southern) flank	☒	☐	☐

Please use the space below to enter any comments or suggest other attributes that might help classify this particular tactical situation. There is no limitation on the amount of text that you can enter.

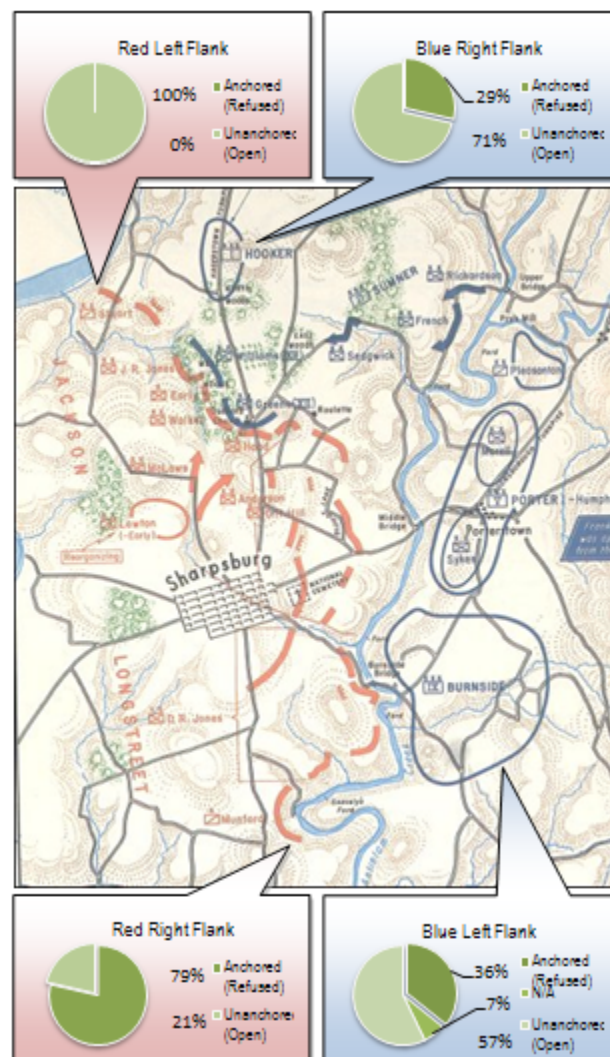
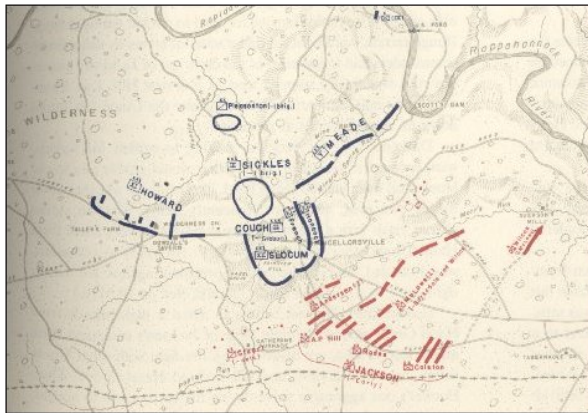


Figure A 1: Results of Survey #1, Question #1, (Antietam) “Are these flanks anchored or unanchored?”



Identifying important attributes of tactical situations.

Anchored and Unanchored Flanks



Chancellorsville, May 1, 1863, situation 0800 hours.

[Source: *Atlas for the American Civil War*. New York: Frederick A. Praeger Publishers, 1964; map 86.]

For this question we would like you to look at the map of the battle of Chancellorsville (left). The Confederate units are indicated in red. The Union units are indicated in blue.

Stuart's cavalry is the Confederate left flank (western flank); Wilcox's infantry brigade is the Confederate right flank (eastern flank). Howard's XI Corps is the Union right flank (western flank) and Meade's V Corps is the Union right flank (eastern flank).

Please select one answer from each of the following. If you feel that the attribute of 'anchored flank' or 'unanchored flank' is present for a particular flank, please select the appropriate box. Select 'N/A' if you feel that 'anchored flanks' are **not** a legitimate attribute for classification of tactical situations.

	Anchored (or Refused) Flank	N/A	Unanchored (or Open) Flank
Red left (western) flank	☐	☐	☒
Red right (eastern) flank	☐	☐	☒
Blue right (western) flank	☐	☐	☒
Blue left (eastern) flank	☒	☐	☐

Please use the space below to enter any comments or suggest other attributes that might help classify this particular tactical situation. There is no limitation on the amount of text that you can enter.

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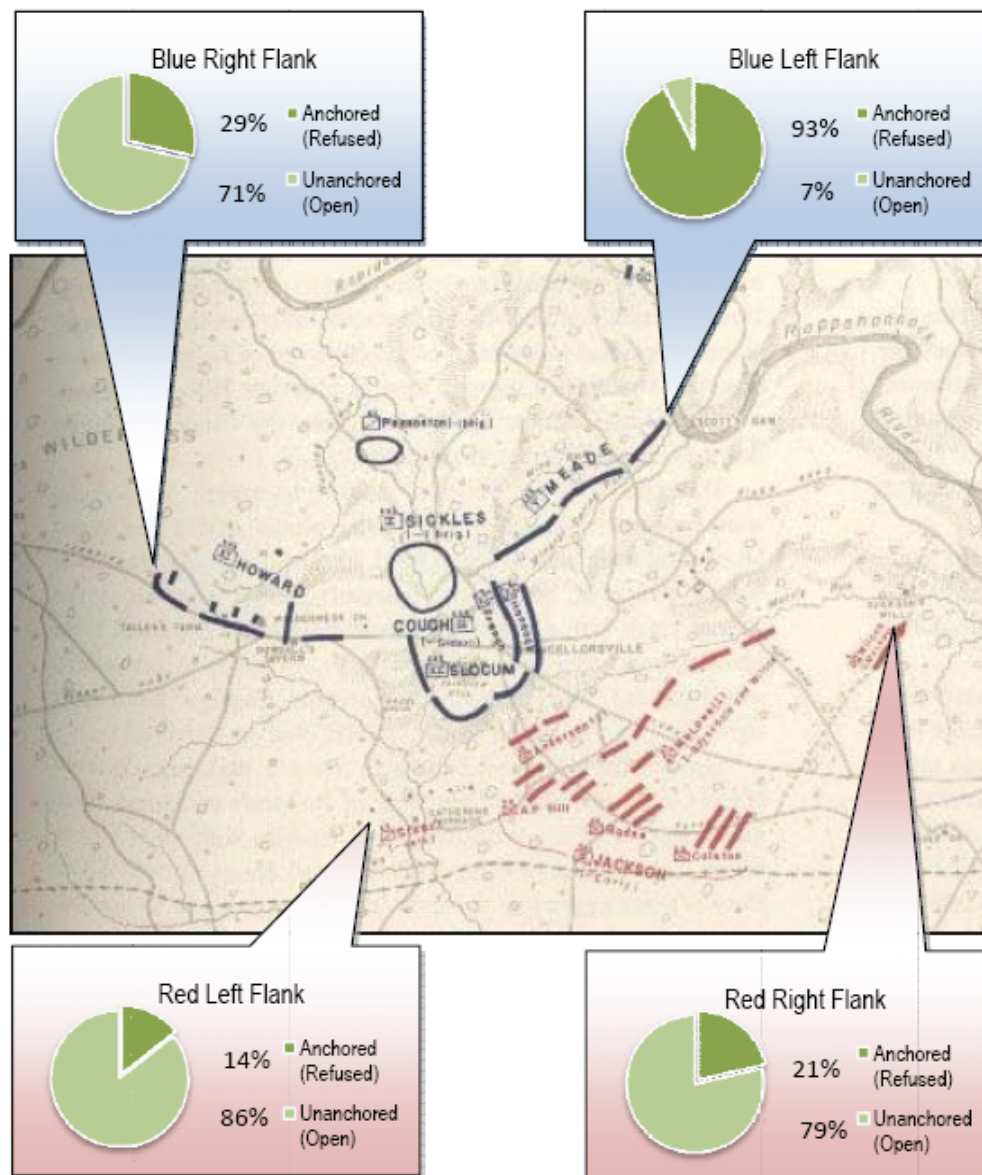
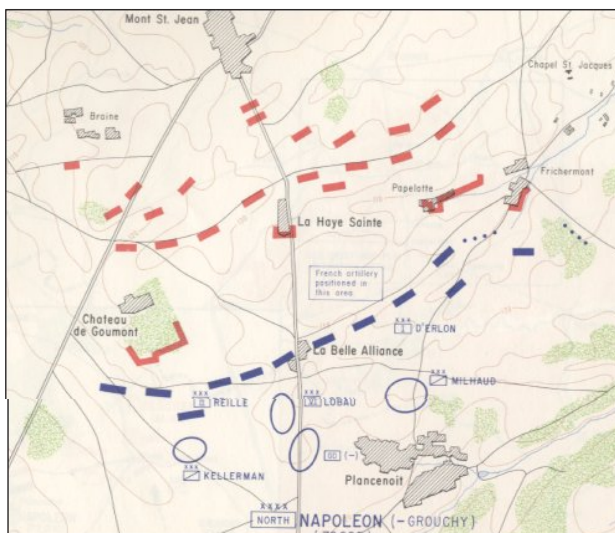


Figure A 2: Results of Survey #1, Question #2, (Chancellorsville) “Are these flanks anchored or unanchored?”



Identifying important attributes of tactical situations.

Anchored and Unanchored Flanks



Waterloo June 18, 1815, situation 1000 hours.

[Source: *Atlas for the Wars of Napoleon*, New York: Frederick A. Praeger Publishers, 1964; map 66.]

For this question we would like you to look at the map of the battle of Waterloo (left). The Anglo-Dutch forces (Wellington) units are indicated in red. The French (Napoleon) units are indicated in blue.

The Anglo-Dutch right flank is at Braine. The Anglo-Dutch left flank is at Frichermont. The French left flank is south of Chateau de Goumont. The French right flank is south of Frichermont.

Please select one answer from each of the following. If you feel that the attribute of 'anchored flank' or 'unanchored flank' is present for a particular flank, please select the appropriate box. Select 'N/A' if you feel that 'anchored flanks' are **not** a legitimate attribute for classification of tactical situations.

	Anchored (or Refused) Flank	N/A	Unanchored (or Open) Flank
Red left (eastern) flank	☐	☐	☒
Red right (western) flank	☒	☐	☒
Blue right (eastern) flank	☐	☐	☒
Blue left (western) flank	☒	☐	☒

Please use the space below to enter any comments or suggest other attributes that might help classify this particular tactical situation. There is no limitation on the amount of text that you can enter.

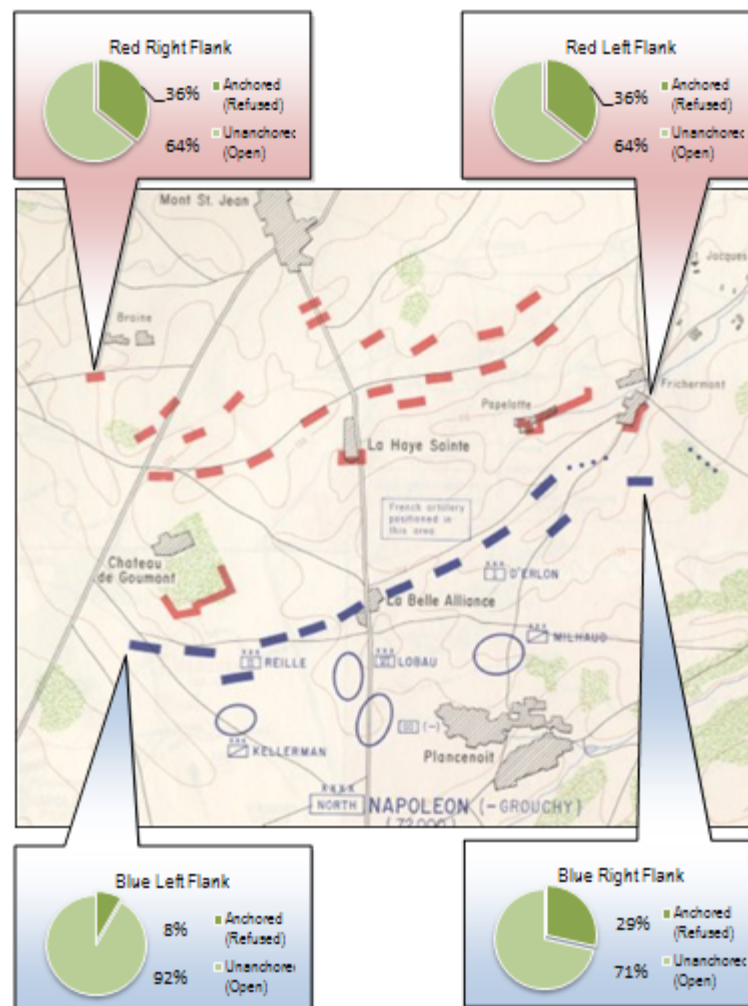
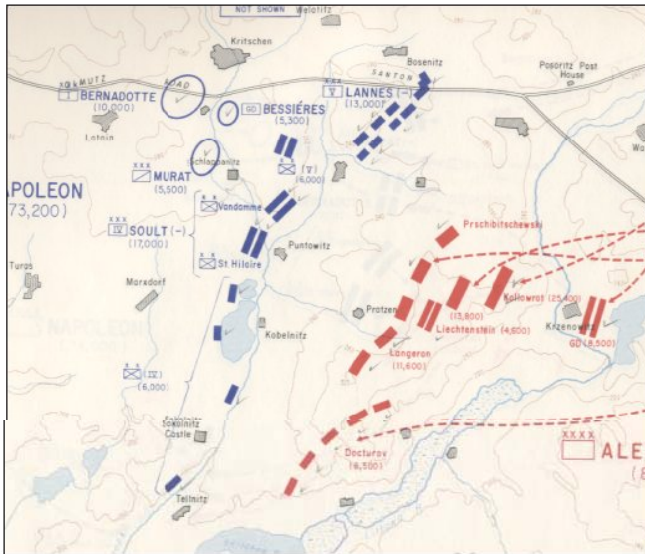


Figure A 3: Results of Survey #1, Question #3, (Waterloo 1000 hours) “Are these flanks anchored or unanchored?”



Identifying important attributes of tactical situations.

Anchored and Unanchored Flanks



Austerlitz 1 December, 1805, situation 1800 hours.

[Source: *Atlas for the Wars of Napoleon*. New York: Frederick A. Praeger Publishers, 1964; map 22.]

For this question we would like you to look at the map of the battle of Austerlitz. The Russian-Austrian forces (Alexander) units are indicated in red. The French (Napoleon) units are indicated in blue.

The Russian-Austrian right flank is Prschibitschewski. The Russian-Austrian left flank is Docturov. The French left flank is Lannes V Corps. The French right flank is north of Telnitz.

Please select one answer from each of the following. If you feel that the attribute of 'anchored flank' or 'unanchored flank' is present for a particular flank, please select the appropriate box. Select 'N/A' if you feel that 'anchored flanks' are **not** a legitimate attribute for classification of tactical situations.

	Anchored (or Refused) Flank	N/A	Unanchored (or Open) Flank
Red left (southern) flank	☐	☐	☒
Red right (northern) flank	☐	☐	☒
Blue right (southern) flank	☐	☐	☒
Blue left (northern) flank	☐	☐	☒

Please use the space below to enter any comments or suggest other attributes that might help classify this particular tactical situation. There is no limitation on the amount of text that you can enter.

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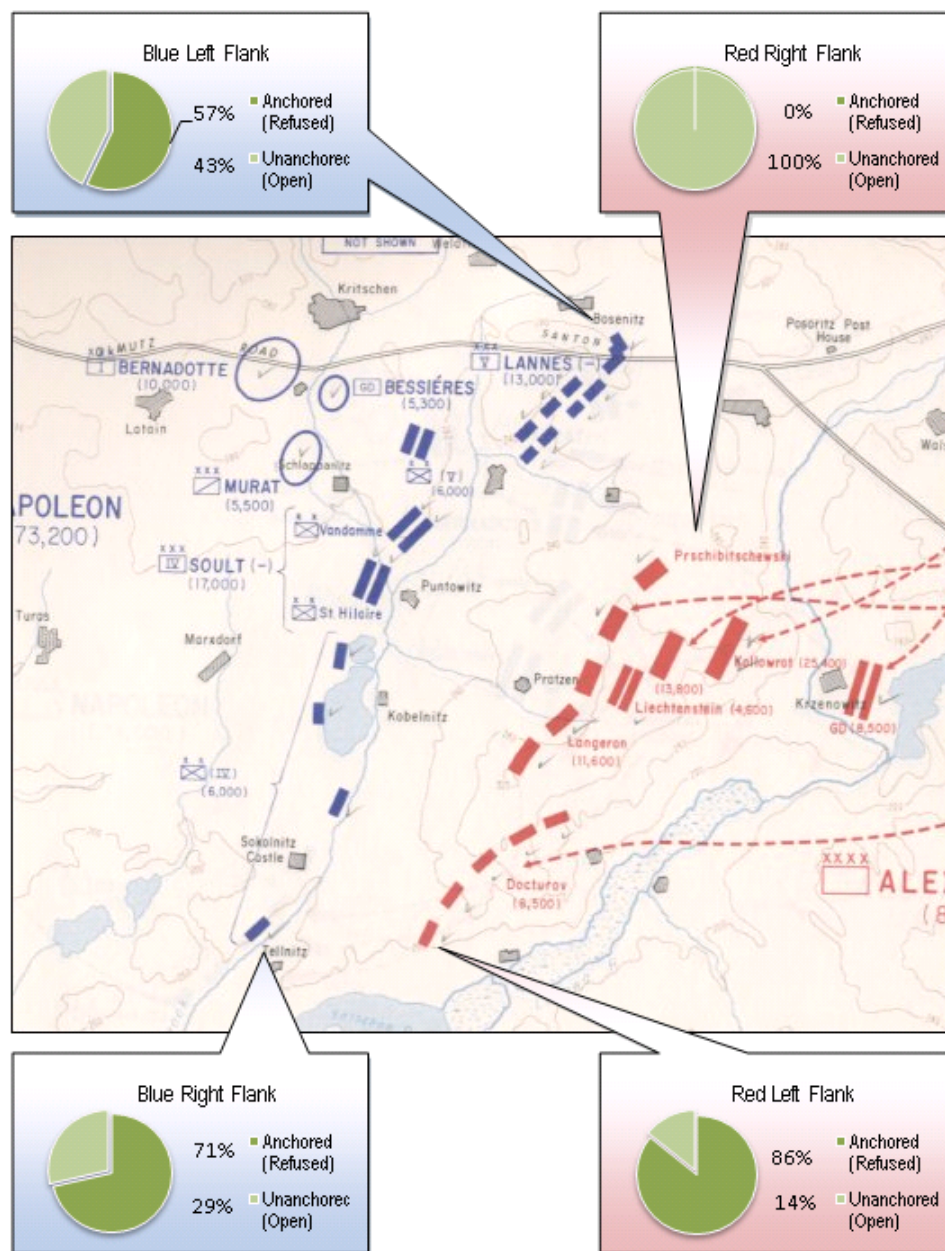
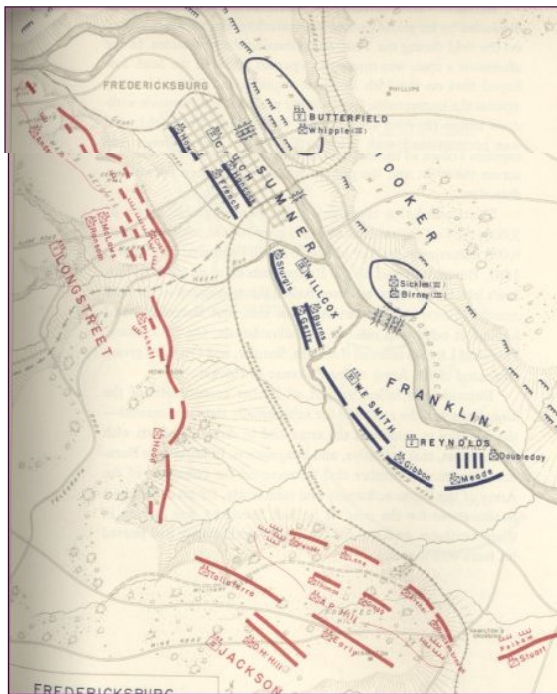


Figure A 4: Results of Survey #1, Question #4, (Austerlitz) “Are these flanks anchored or unanchored?”



Identifying important attributes of tactical situations.

Anchored and Unanchored Flanks



Fredericksburg 1 December, 1862, situation 1200 hours.

[Source: *Atlas for the American Civil War*. New York: Frederick A. Praeger Publishers, 1964; map 72b.]

For this question we would like you to look at the map of the battle of Fredericksburg. The Confederate forces (Lee) units are indicated in red. The Union (Burnside) units are indicated in blue.

Please select one answer from each of the following. If you feel that the attribute of 'anchored flank' or 'unanchored flank' is present for a particular flank, please select the appropriate box. Select 'N/A' if you feel that 'anchored flanks' are **not** a legitimate attribute for classification of tactical situations.

	Anchored (or Refused) Flank	N/A	Unanchored (or Open) Flank
Red left (northern) flank	☒	☐	☐
Red right (southern) flank	☒	☐	☐
Blue right (northern) flank	☒	☐	☐
Blue left (southern) flank	☒	☐	☐

Please use the space below to enter any comments or suggest other attributes that might help classify this particular tactical situation. There is no limitation on the amount of text that you can enter.

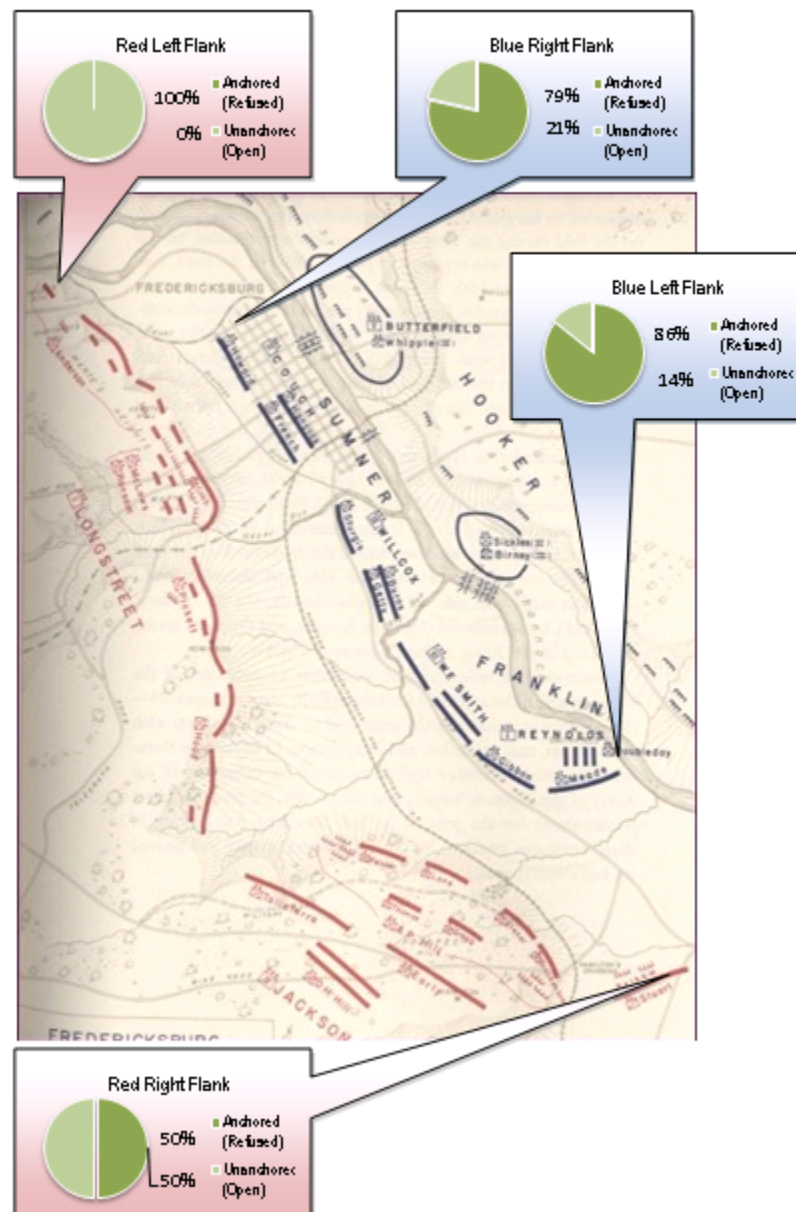
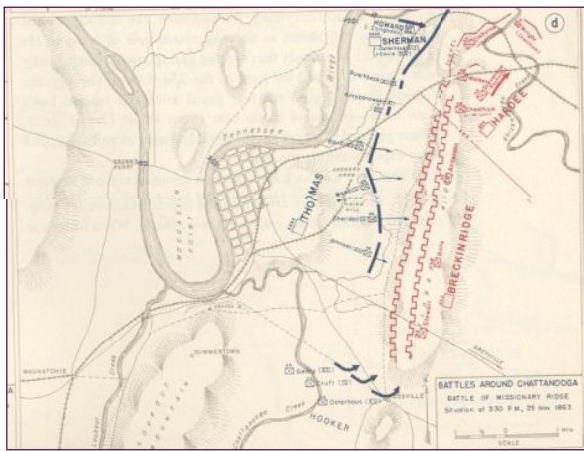


Figure A 5: Results of Survey #1, Question #5, (Fredericksburg)
 “Are these flanks anchored or unanchored?”



Identifying important attributes of tactical situations.

Anchored and Unanchored Flanks



Chattanooga 25 November, 1863, situation 1530 hours.

[Source: *Atlas for the American Civil War*. New York: Frederick A. Praeger Publishers, 1964; map 116d.]

For this question we would like you to look at the map of the battle of Chattanooga. The Confederate forces (Bragg) units are indicated in red. The Union (Grant) units are indicated in blue.

Please select one answer from each of the following. If you feel that the attribute of 'anchored flank' or 'unanchored flank' is present for a particular flank, please select the appropriate box. Select 'N/A' if you feel that 'anchored flanks' are **not** a legitimate attribute for classification of tactical situations.

	Anchored (or Refused) Flank	N/A	Unanchored (or Open) Flank
Red left (southern) flank	☐	☐	☒
Red right (northern) flank	☐	☐	☒
Blue right (southern) flank	☐	☐	☒
Blue left (northern) flank	☐	☐	☒

Please use the space below to enter any comments or suggest other attributes that might help classify this particular tactical situation. There is no limitation on the amount of text that you can enter.

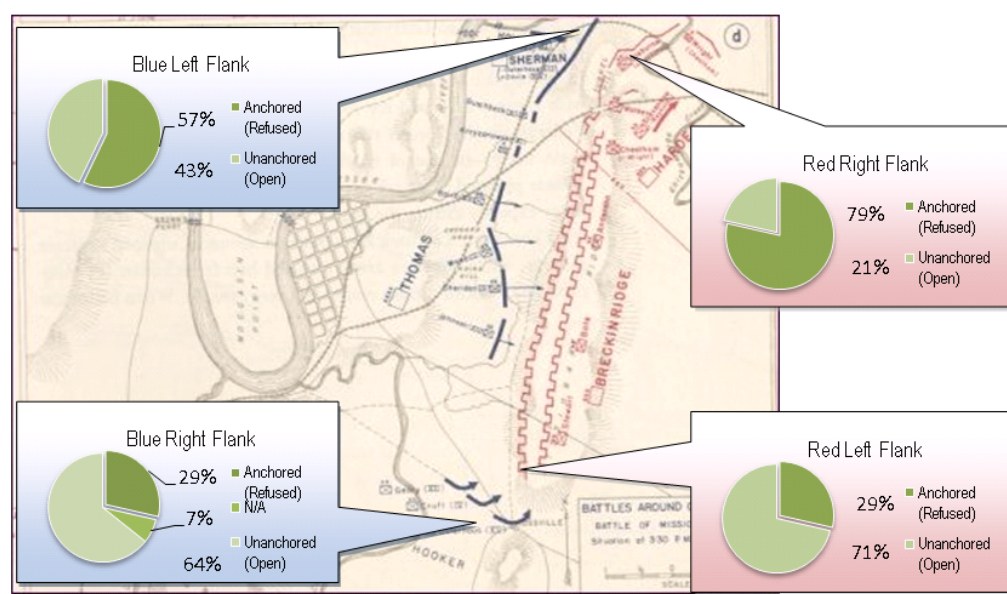


Figure A 6: Results of Survey #1, Question #6, (Chattanooga) “Are these flanks anchored or unanchored?”



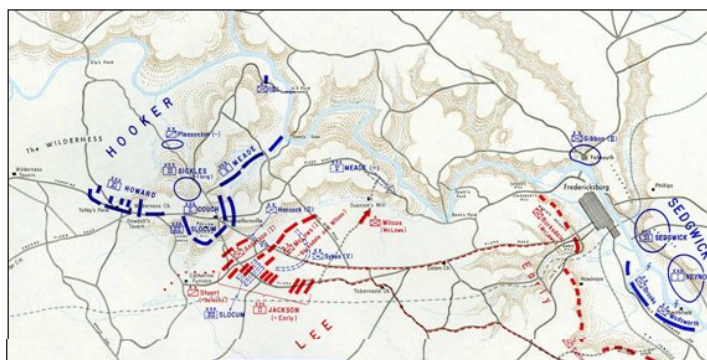
Identifying important attributes of tactical situations.

Interior Lines

The next series of survey questions are about the attribute candidate of 'interior lines'.

The following is a definition of 'interior lines':

Interior Lines: The military circumstance of either being able to move over a shorter distance to execute maneuvers and effect reinforcements than the enemy or possessing a more efficient transportation method or faster units than the enemy.



Chancellorsville situation about 1830, 1 May, 1863.

[Source: *Atlas for the American Civil War*. New York: Frederick A. Praeger Publishers, 1964; map 86.]

For this question we would like you to look at the map of the battle of Chancellorsville. The Confederate units are indicated in red. The Union units are indicated in blue.

Please select one answer from each of the following. If you feel that the attribute of 'interior lines' is present for a particular force, please select the appropriate box. Select 'N/A' if you feel that 'interior lines' are not a legitimate attribute for classification of tactical situations.

	Has Interior Lines	N/A	Does Not Have Interior Lines
Confederate (red)	☒	☐	☐
Union (blue)	☐	☐	☒

Please use the space below to enter any comments or suggest other attributes that might help classify this particular tactical situation. There is no limitation on the amount of text that you can enter.

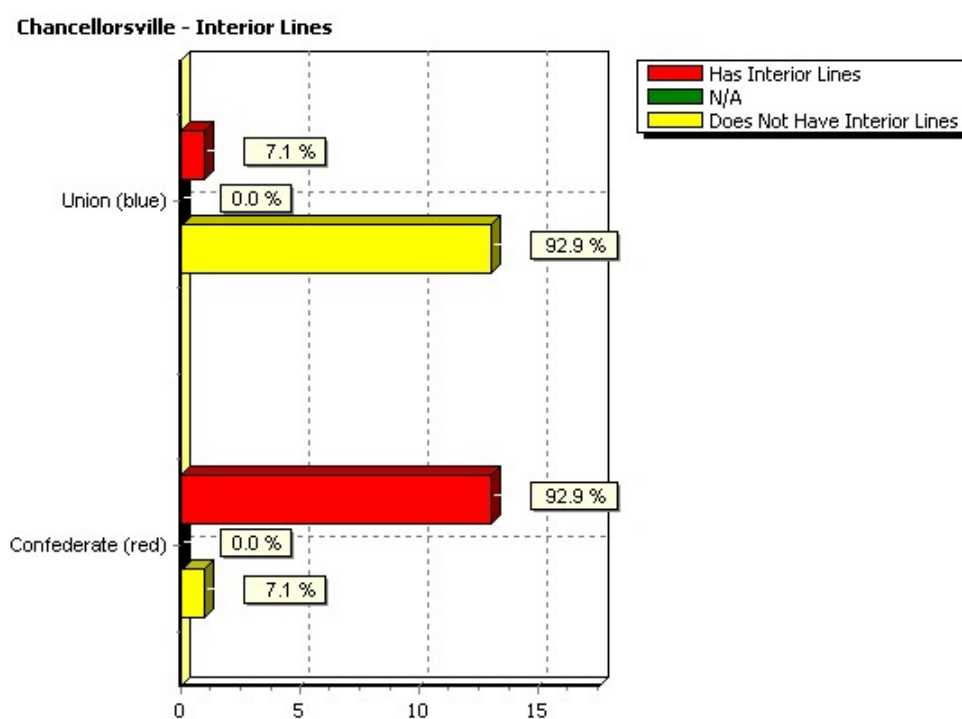
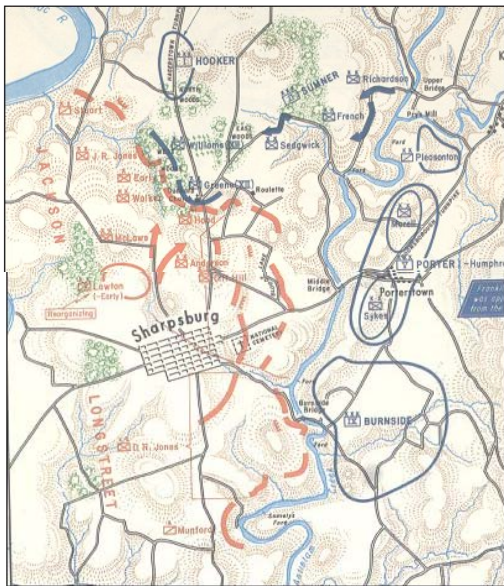


Figure A 7: Results of Survey #1, Question #7, (Chancellorsville) “Does the Union have Interior Lines, or N/A? Do the Confederates have interior lines or, N/A?”



Identifying important attributes of tactical situations.

Interior Lines



Antietam situation about 0900, 17 September 1862.

[Source: *Atlas for the American Civil War*. Wayne, NJ: Avery Publishing Group, 1986; map 14a]

For this question we would like you to look at the map of the battle of Antietam. The **Confederate units are indicated in red**. The **Union units are indicated in blue**.

Please select one answer from each of the following. If you feel that the attribute of 'interior lines' is present for a particular force, please select the appropriate box. Select 'N/A' if you feel that 'interior lines' are **not** a legitimate attribute for classification of tactical situations.

	Has Interior Lines	N/A	Does Not Have Interior Lines
Confederate (red)	☒	☐	☐
Union (blue)	☐	☐	☒

Please use the space below to enter any comments or suggest other attributes that might help classify this particular tactical situation. There is no limitation on the amount of text that you can enter.

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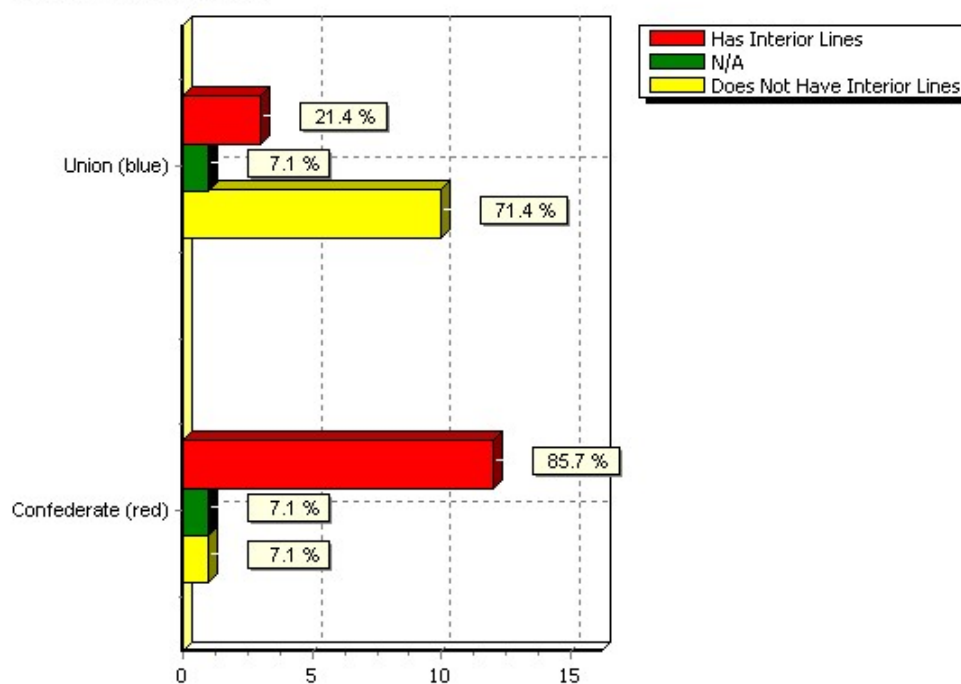
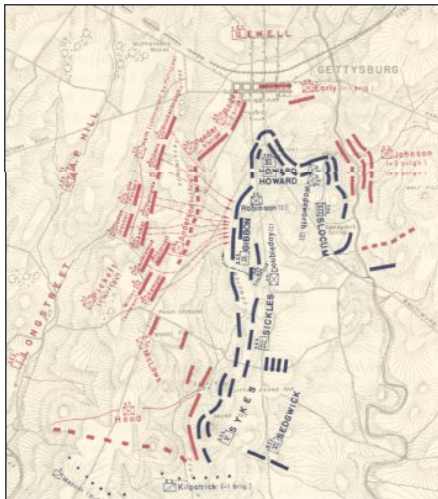
Antietam - Interior Lines

Figure A 8: Results of Survey #1, Question #8, (Antietam) “Does the Union have Interior Lines, or N/A? Do the Confederates have interior lines or, N/A?”



Identifying important attributes of tactical situations.

Interior Lines



Gettysburg situation about 1430, 3 July 1863.

[Source: *Atlas for the American Civil War*. New York: Frederick A. Praeger Publishers, 1964; map 98.]

For this question we would like you to look at the map of the battle of Gettysburg. The **Confederate units** are indicated in red. The **Union units** are indicated in blue.

Please select one answer from each of the following. If you feel that the attribute of 'interior lines' is present for a particular force, please select the appropriate box. Select 'N/A' if you feel that 'interior lines' are **not** a legitimate attribute for classification of tactical situations.

	Has Interior Lines	N/A	Does Not Have Interior Lines
Confederate (red)	☐	☐	☒
Union (blue)	☒	☐	☐

Please use the space below to enter any comments or suggest other attributes that might help classify this particular tactical situation. There is no limitation on the amount of text that you can enter.

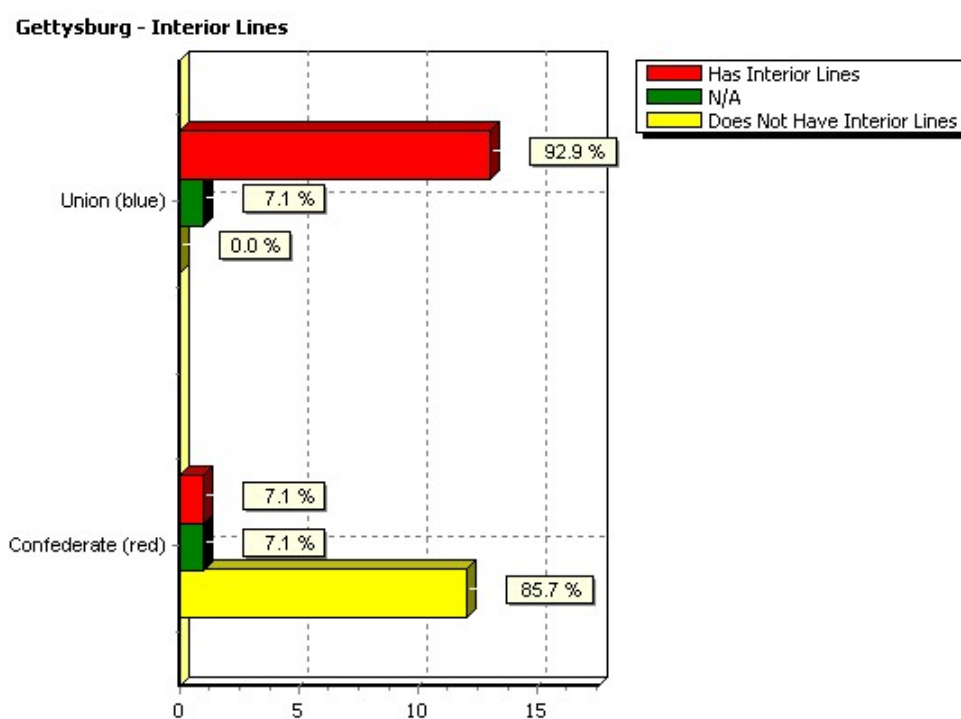
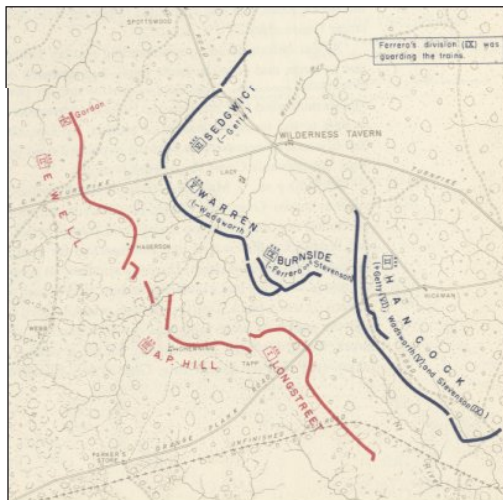


Figure A 9: Results of Survey #1, Question #9, (Gettysburg) “Does the Union have Interior Lines, or N/A? Do the Confederates have interior lines or, N/A?”



Identifying important attributes of tactical situations.

Interior Lines



The Wilderness situation about 1400, 5 May, 1864.

[Source: *Atlas for the American Civil War*. New York: Frederick A. Praeger Publishers, 1964; map 122b.]

For this question we would like you to look at the map of the battle of the Wilderness. The Confederate units are indicated in red. The Union units are indicated in blue.

Please select one answer from each of the following. If you feel that the attribute of 'interior lines' is present for a particular force, please select the appropriate box. Select 'N/A' if you feel that 'interior lines' are **not** a legitimate attribute for classification of tactical situations.

	Has Interior Lines	N/A	Does Not Have Interior Lines
Confederate (red)	☐	☐	☒
Union (blue)	☐	☐	☒

Please use the space below to enter any comments or suggest other attributes that might help classify this particular tactical situation. There is no limitation on the amount of text that you can enter.

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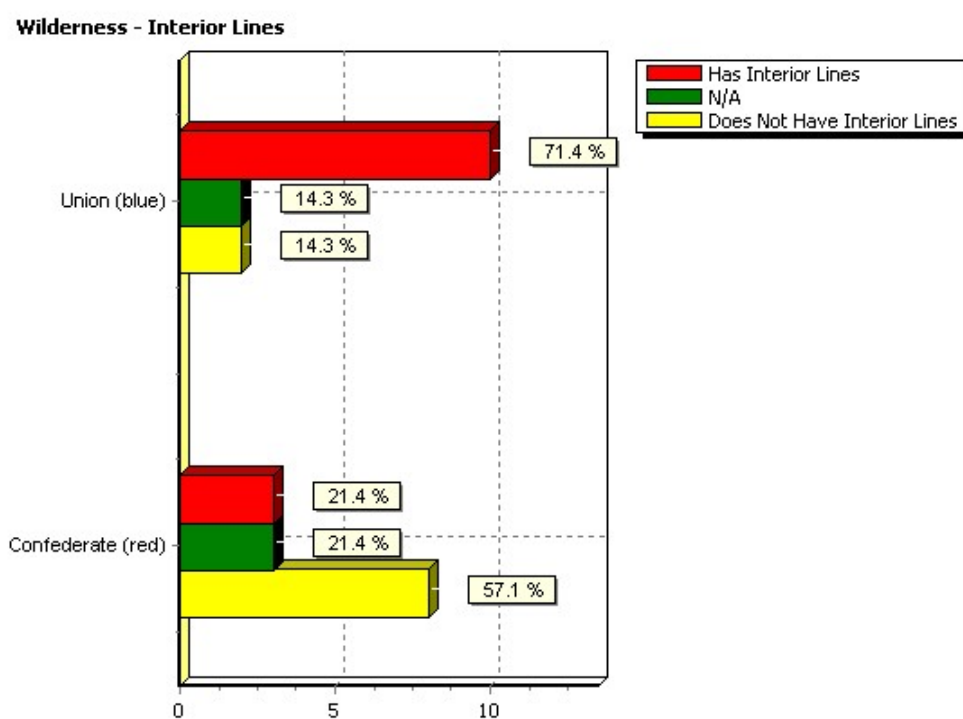
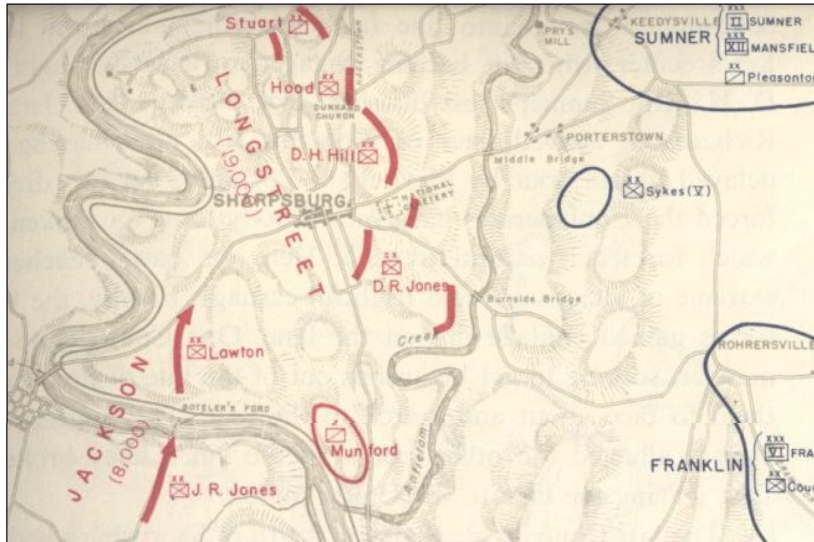


Figure A 10: Results of Survey #1, Question #10, (The Wilderness)
“Does the Union have Interior Lines, or N/A? Do the Confederates have interior lines or, N/A?”



Identifying important attributes of tactical situations.

Restricted Avenues of Attack & Restricted Avenues of Retreat



Antietam situation about 0600, 16 September 1862.

[Source: *Atlas for the American Civil War*. New York: Frederick A. Praeger Publishers, 1964; map 67a.]

In this series of survey questions we are interested in 'attributes' that describe restricted avenues of attack and restricted avenues of retreat. There may be various causes that restrict a force's ability to attack or retreat; these include bodies of water and hills or any other impediment to movement.

For this question we would like you to look at the map of the preliminary movements at Antietam. The Confederate units are indicated in red. The Union units are indicated in blue.

Antietam Creek runs north-south between the Confederate and Union forces. There are four bridges across Antietam Creek.

The Potomac River is the wide body of water west of Sharpsburg. It has one bridge and one ford. Assume that the Confederate line of retreat is to the south. Assume that the Union line of retreat is to the east.

Please select one answer from each of the following. For both attack and retreat for each side you may select 'severely restricted', 'restricted' or 'not restricted'. Select 'N/A' if you feel that 'restricted avenues of attack and retreat' are **not** a legitimate attribute for classification of tactical situations.

	Severely restricted	Restricted	N/A	Not restricted
Confederate line of retreat	☒	☐	☐	☐
Confederate line of attack	☐	☒	☐	☐
Union line of retreat	☐	☐	☐	☒
Union line of attack	☐	☒	☐	☐

Please use the space below to enter any comments or suggest other attributes that might help classify this particular tactical situation. There is no limitation on the amount of text that you can enter.

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68%

Antietam - Lines of Attack & Retreat

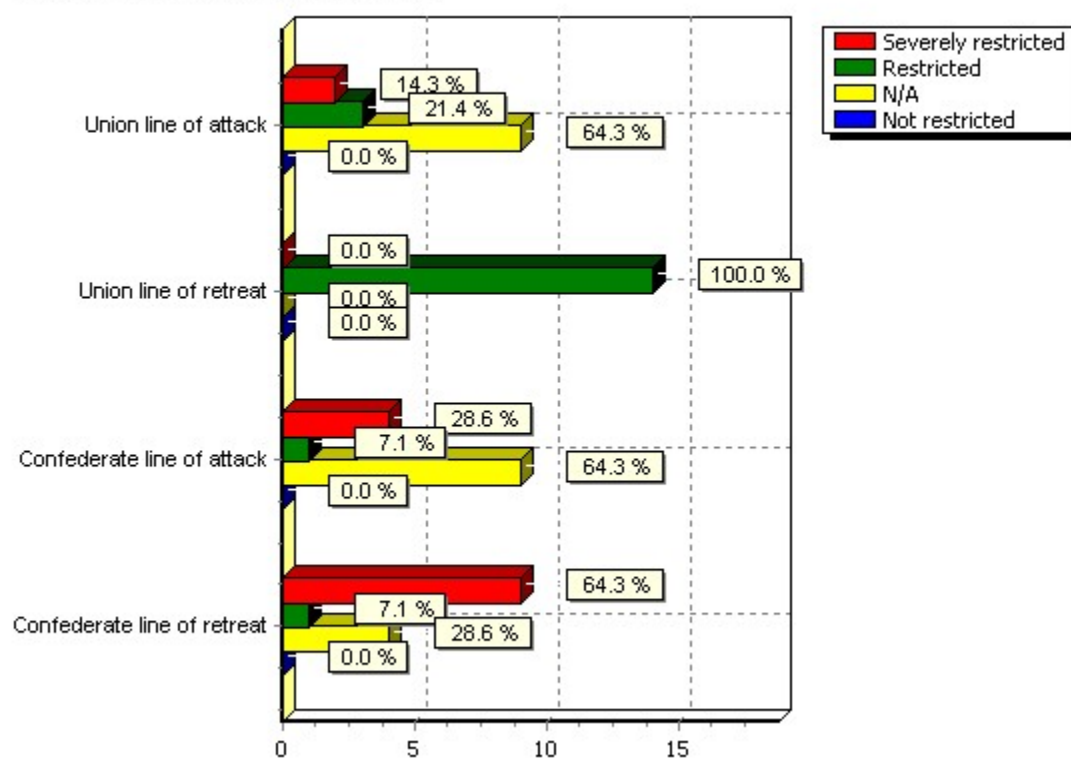
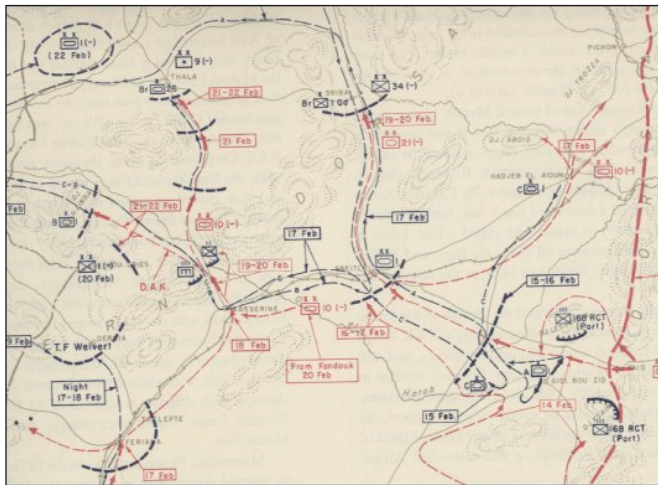


Figure A 11: Results of Survey #1, Question #11, (Antietam) “Does the Union have restricted avenues of attack, restricted avenues of retreat or N/A? Do the Confederates have restricted avenues of attack, restricted avenues of retreat or, N/A?”



Identifying important attributes of tactical situations.

Restricted Avenues of Attack & Restricted Avenues of Retreat



The battle of Kasserine Pass, operations 14-22 February 1943.

[Source: *The West Point Atlas of American Wars, Volume II*, New York: Frederick A. Praeger Publishers, 1964; map 85.]

In this series of survey questions we are interested in 'attributes' that describe restricted avenues of attack and restricted avenues of retreat.

For this question we would like you to look at the map of the operations around Kasserine Pass in North Africa. The Axis units are indicated in red. The Allied units are indicated in blue.

The Western Dorsal Mountains run from the southwest to the northeast. Assume that the Axis line of retreat is towards the east and the Allied line of retreat is towards the west.

Please select one answer from each of the following. For both attack and retreat for each side you may select 'severely restricted', restricted or 'not restricted'. Select 'N/A' if you feel that 'restricted

avenues of attack and retreat' are **not** a legitimate attribute for classification of tactical situations.

	Severely restricted	Restricted	N/A	Not restricted
Axis line of retreat	☐	☒	☐	☐
Axis line of attack	☒	☐	☐	☐
Allied line of retreat	☒	☐	☐	☐
Allied line of attack	☒	☐	☐	☐

Please use the space below to enter any comments or suggest other attributes that might help classify this particular tactical situation. There is no limitation on the amount of text that you can enter.

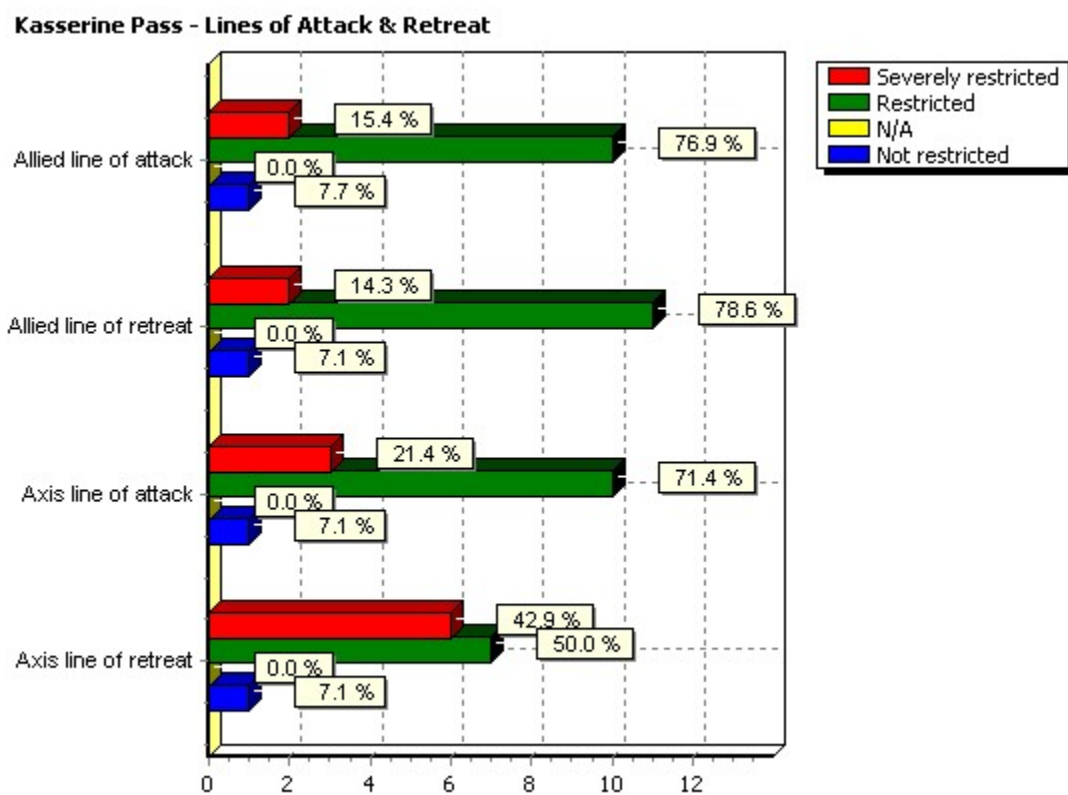
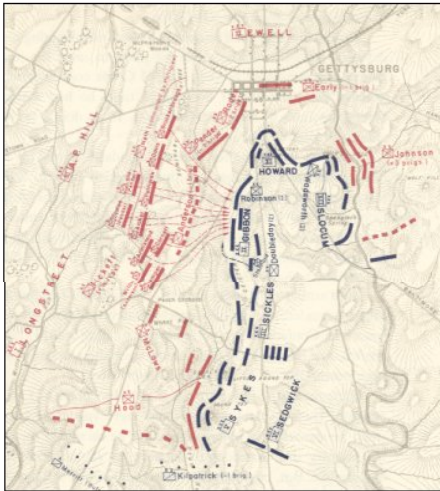


Figure A 12: Results of Survey #1, Question #12, (Kasserine Pass) “Do the Allies have restricted avenues of attack, restricted avenues of retreat or N/A? Do the Axis have restricted avenues of attack, restricted avenues of retreat or, N/A?”



Identifying important attributes of tactical situations.

Restricted Avenues of Attack & Restricted Avenues of Retreat



Gettysburg situation about 1430, 3 July 1863.

[Source: *Atlas for the American Civil War*. New York: Frederick A. Praeger Publishers, 1964; map 98.]

For this question we would like you to look at the map of the battle of Gettysburg. The **Confederate units (Lee)** are indicated in red. The **Union units (Meade)** are indicated in blue.

In this series of survey questions we are interested in 'attributes' that describe restricted avenues of attack and restricted avenues of retreat.

Assume that the Confederate line of retreat is towards the west and the Union line of retreat is towards the east.

Please select one answer from each of the following. For both attack and retreat for each side you may select 'severely restricted', restricted or 'not restricted'. Select 'N/A' if you feel that 'restricted avenues of attack and retreat' are **not** a legitimate attribute for classification of tactical situations.

	Severely restricted	Restricted	N/A	Not restricted
Confederate line of retreat	☐	☐	☐	☒
Confederate line of attack	☐	☐	☐	☒
Union line of retreat	☐	☐	☐	☒
Union line of attack	☐	☐	☐	☒

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79%

Gettysburg - Lines of Attack & Retreat

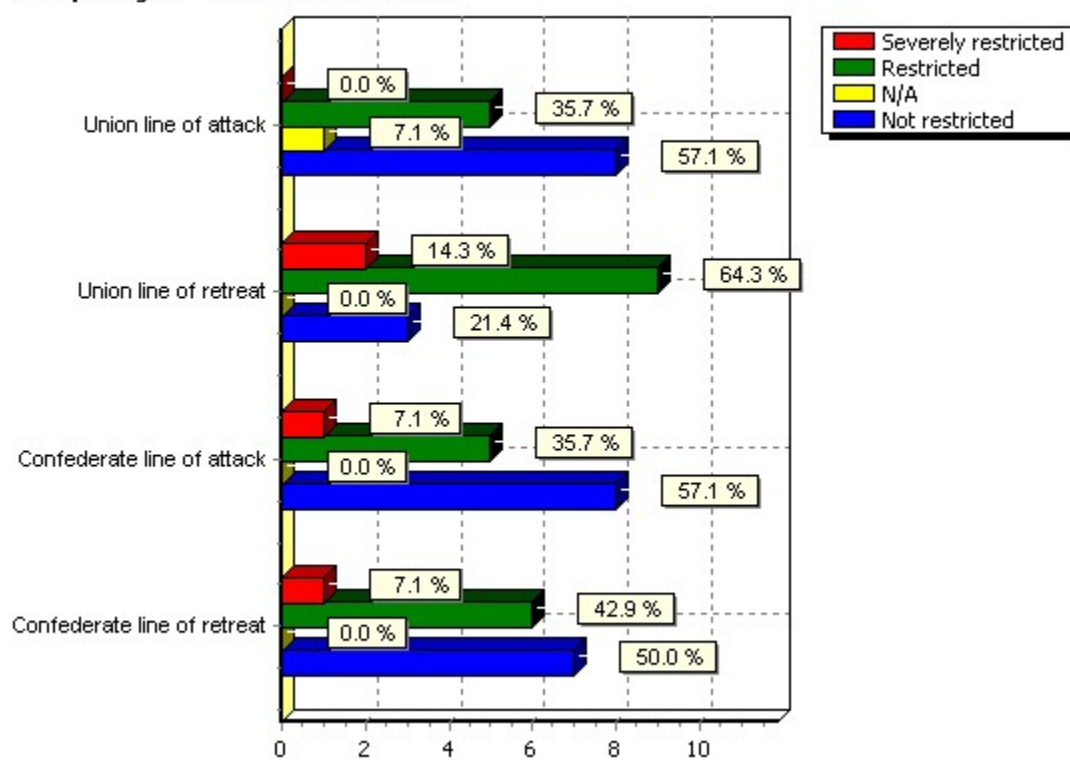
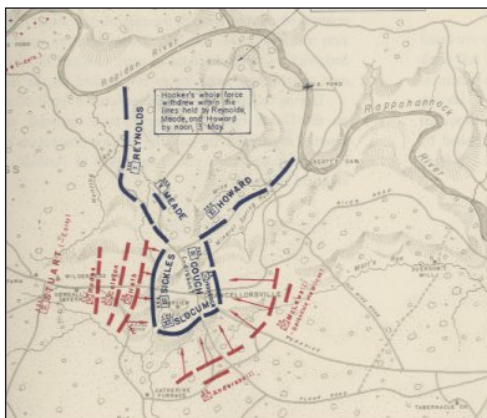


Figure A 13: Results of Survey #1, Question #13, (Gettysburg) “Does the Union have restricted avenues of attack, restricted avenues of retreat or N/A? Do the Confederates have restricted avenues of attack, restricted avenues of retreat or, N/A?”



Identifying important attributes of tactical situations.

Restricted Avenues of Attack & Restricted Avenues of Retreat



Chancellorsville situation early 3 May 1863.

[Source: *Atlas for the American Civil War*. New York: Frederick A. Praeger Publishers, 1964; map 88.]

For this question we would like you to look at the map of the battle of Chancellorsville (left). The **Confederate units (Lee)** are indicated in red. The **Union units (Hooker)** are indicated in blue.

In this series of survey questions we are interested in 'attributes' that describe restricted avenues of attack and restricted avenues of retreat.

Assume that the Confederate line of retreat is towards the south and east and the Union line of retreat is towards the north, across the Rappahannock River.

Please select one answer from each of the following. For both attack and retreat for each side you may select 'severely restricted', restricted or 'not restricted'. Select 'N/A' if you feel that 'restricted avenues of attack and retreat' are **not** a legitimate attribute for classification of tactical situations.

	Severely restricted	Restricted	N/A	Not restricted
Confederate line of retreat	☐	☐	☐	☒
Confederate line of attack	☐	☐	☐	☒
Union line of retreat	☒	☐	☐	☐
Union line of attack	☐	☐	☐	☒

Please use the space below to enter any comments or suggest other attributes that might help classify this particular tactical situation. There is no limitation on the amount of text that you can enter.

Chancellorsville - Lines of Attack & Retreat

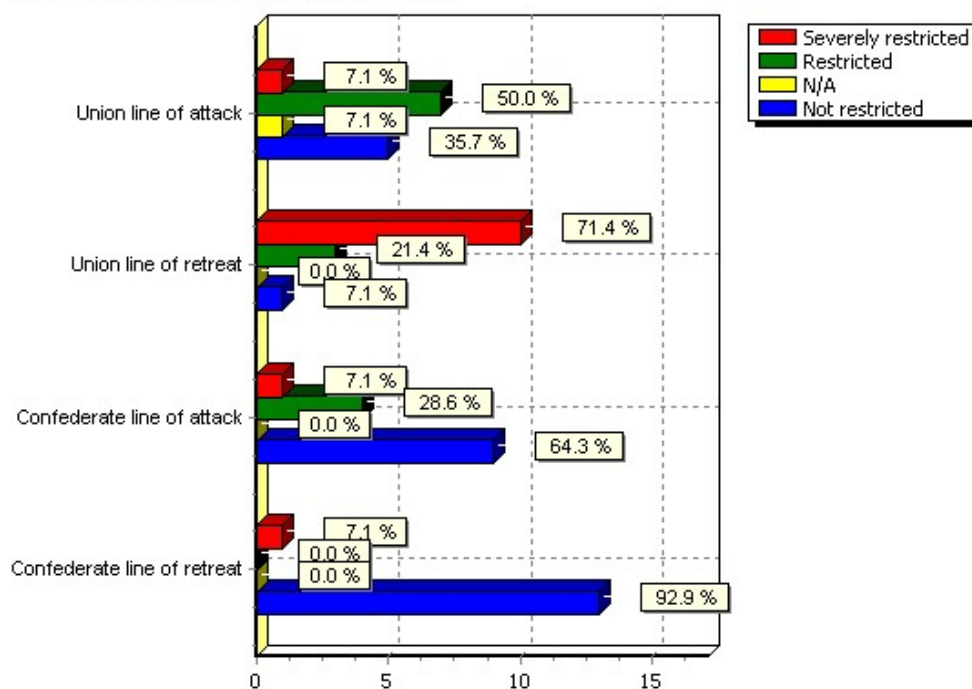
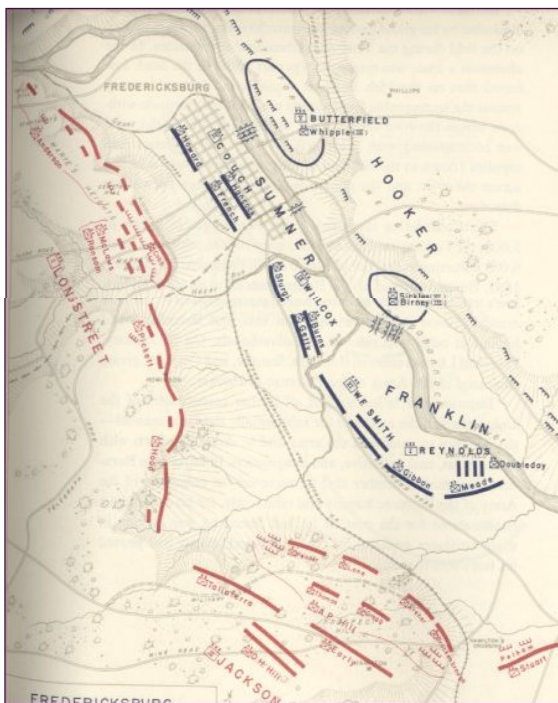


Figure A 14: Results of Survey #1, Question #14, (Chancellorsville)
 “Does the Union have restricted avenues of attack, restricted avenues of retreat or N/A? Do the Confederates have restricted avenues of attack, restricted avenues of retreat or, N/A?”



Identifying important attributes of tactical situations.

Restricted Avenues of Attack & Restricted Avenues of Retreat



Fredericksburg 13 December, 1862, situation 1300 hours.

[Source: *Atlas for the American Civil War*. New York: Frederick A. Praeger Publishers, 1964; map 72b.]

For this question we would like you to look at the map of the battle of Chancellorsville. The **Confederate units (Lee)** are indicated in red. The **Union units (Burnside)** are indicated in blue.

In this series of survey questions we are interested in 'attributes' that describe restricted avenues of attack and restricted avenues of retreat.

Assume that the Confederate line of retreat is towards the west and the Union line of retreat is towards the east, across the Rappahannock River.

Please select one answer from each of the following. For both attack and retreat for each side you may select 'severely restricted', restricted or 'not restricted'. Select 'N/A' if you feel that 'restricted avenues of attack and retreat' are **not** a legitimate attribute for classification of tactical situations.

	Severely restricted	Restricted	N/A	Not restricted
Confederate line of retreat	☐	☐	☐	☒
Confederate line of attack	☐	☐	☐	☒
Union line of retreat	☒	☐	☐	☐
Union line of attack	☐	☐	☐	☒

Please use the space below to enter any comments or suggest other attributes that might help classify this particular tactical situation. There is no limitation on the amount of text that you can enter.

Fredericksburg - Lines of Attack & Retreat

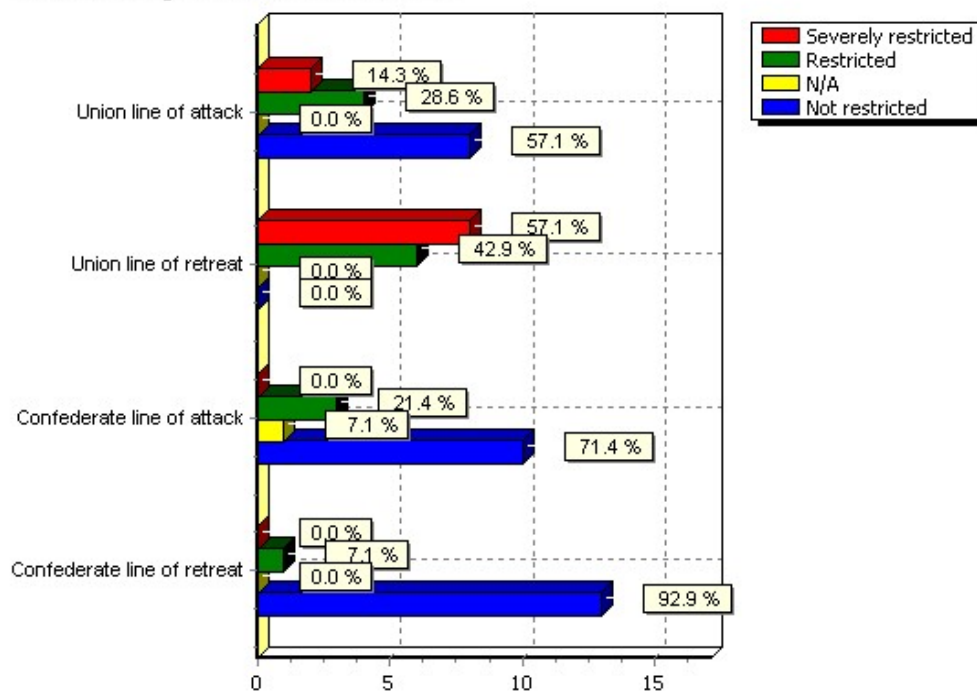
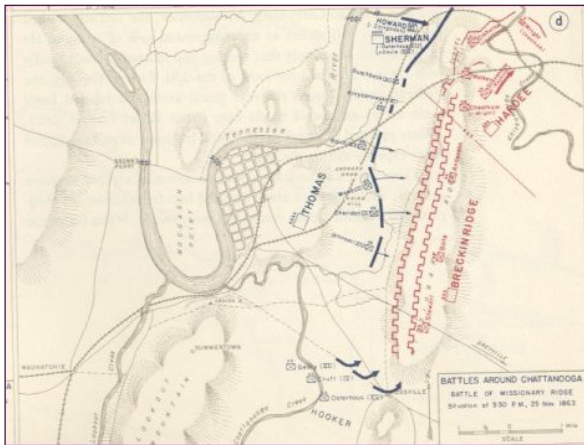


Figure A 15: Results of Survey #1, Question #15, (Fredericksburg) “Does the Union have restricted avenues of attack, restricted avenues of retreat or N/A? Do the Confederates have restricted avenues of attack, restricted avenues of retreat or, N/A?”



Identifying important attributes of tactical situations.

Restricted Avenues of Attack & Restricted Avenues of Retreat



Chattanooga 25 November, 1863, situation 1530 hours.

[Source: *Atlas for the American Civil War*. New York: Frederick A. Praeger Publishers, 1964; map 116d.]

For this question we would like you to look at the map of the battle of Chattanooga. The **Confederate units (Bragg)** are indicated in red. The **Union units (Grant)** are indicated in blue.

In this series of survey questions we are interested in 'attributes' that describe restricted avenues of attack and restricted avenues of retreat.

Assume that the Confederate line of retreat is towards the east and the Union line of retreat is towards the west.

Please select one answer from each of the following. For both attack and retreat for each side you may select 'severely restricted', restricted or 'not restricted'. Select 'N/A' if you feel that 'restricted avenues of attack and retreat' are **not** a legitimate attribute for classification of tactical situations.

	Severely restricted	Restricted	N/A	Not restricted
Confederate line of retreat	☐	☐	☐	☒
Confederate line of attack	☐	☐	☐	☒
Union line of retreat	☐	☒	☐	☐
Union line of attack	☐	☐	☐	☒

Please use the space below to enter any comments or suggest other attributes that might help classify this particular tactical situation. There is no limitation on the amount of text that you can enter.

Chattanooga - Lines of Attack & Retreat

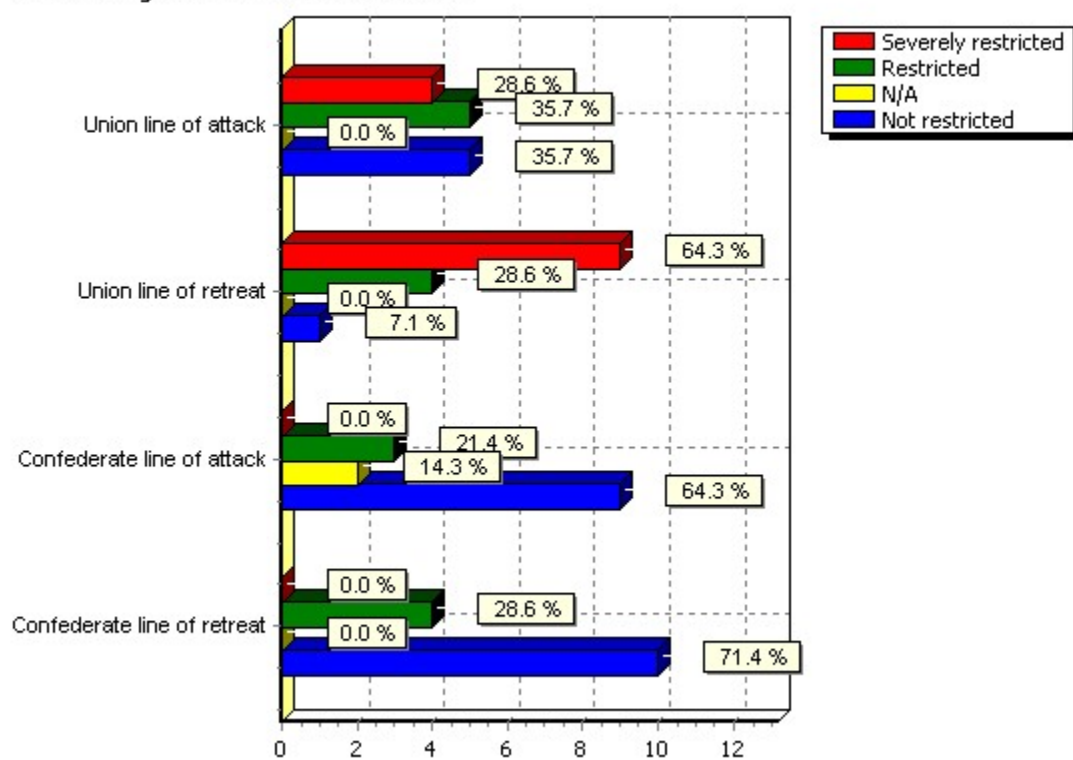


Figure A 16: Results of Survey #1, Question #16, (Chattanooga) “Does the Union have restricted avenues of attack, restricted avenues of retreat or N/A? Do the Confederates have restricted avenues of attack, restricted avenues of retreat or, N/A?”



Identifying important attributes of tactical situations.

Please use the space below to enter any comments or questions about this survey. There is no limitation on the amount of text that you can enter.

If you have any other comments or would like to send an email: dsidran@cs.uiowa.edu.

Thank you very much for taking the time to complete this survey!
Your input is very much appreciated!

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 100%

The SMEs were encouraged to write ‘free-form’ comments about the questions and the survey in general (the comments, and indeed, the SME’s specific survey responses, were anonymous). Some of the more interesting comments appear below:

In response to Antietam anchored flanks: “Red is clearly anchored on river lines, while blue is anchored on the terrain/hills.” “Red extends both left and right to significant geographic features so both are anchored.” “Stuart and Hooker anchored on the Potomac shoreline. The river is unfordable here.” “Munford and Burnside are anchored on Antietam Creek, which was (incorrectly!) thought to be unfordable below Snavelly's Ford.”

In response to Chancellorsville anchored flanks: “Because the Confederate Army is attacking (a superior force!) Lee's open flanks are tactically irrelevant -- Hooker cannot exploit Lee's positional vulnerability because he is unaware of it. Jackson is well aware of Hooker's vulnerability, and is about to smash him in one of the most brilliant flanking maneuvers of the Civil War.”

In response to Fredericksburg anchored flanks: “Red positions take full advantage of the terrain here. Dug into trenches with the high ground and supporting cannon and anchored on both ends by the river and rough ground the south has positional advantage. Blue is advancing against a nearly immobile defender therefore blue flanks are relatively unimportant.” “Lee's left is anchored by both the Rappahannock and a strong position on high ground. His right is relatively open, because Burnside's artillery dominates the low ground. The Union flanks are also anchored by the river and a canal, but this is irrelevant because Burnside is going to make a series of frontal assaults that will be defeated in detail.”

In response to Chancellorsville interior lines: “Lee's position is, indeed, the classic textbook illustration of both ‘Interior Lines’ and ‘Economy of Force.’”

In response to Antietam interior lines: “Lee not only HAD the advantage of interior lines, he exploited it, by masterfully switching his reserves to the most threatened sectors.”

In response to Gettysburg interior lines: “Meade has made excellent use of terrain in this "fish-hook" position, but failed to exploit the tactical advantage of maneuvering against either of Lee's dangling flanks, being reluctant to commit Sedgewick's powerful corps (The Army's operational reserve).”

In response to Antietam restricted avenues of retreat: “Only one bridge and one ford will not support massive red retreat. Road jams will occur and military cohesion could be lost. Blue has easy access to a prepared road net so retreat is easy. The hilly terrain and relative lack of roads between red and blue will tend to restrict movement for everyone. Lines of sight are also short and confused. Without modern communications redirection of forces will be hard on

both sides.” “Lee is trapped with his back to a swollen river, with a deep rocky ford and a broken bridge. Line of attack is irrelevant, because he must fight a defensive battle. The Confederate position was open to attack across its entire front, but McClellan's failure to coordinate his attacks, or exercise any effective command and control, led to a series of piecemeal assaults, and a marginal win that should have been a decisive victory.”

In response to Kasserine Pass restricted avenues of approach and retreat: “In this case terrain is everything. Both sides must fight in the heavily restricted valleys but as the battle moves west the Allied units will come into more open country which will provide greater movement options. The further the Axis forces move the harder the retreat route will become.”

Overall comments about Survey #1 in general:

“This was very interesting! I have studied such situations/scenarios before and they have always led to fascinating discussions. I am interested in your use of these surveys. A few things occurred to me while doing the survey. The physical layout of the situation can clearly determine anchored/unanchored flanks, interior/exterior lines, and axes of attack/retreat. However, disposition/composition of the units play into whether the benefits/risks of the above attributes could be mitigated/exploited. Truly great military leaders can get a feel for this aspect much better than the average ‘Joe.’”

“An interesting project.”

“This survey was a lot of fun, not bad for Friday the 13th! I believe the basic premise is fundamentally flawed in several respects. Considerations of anchored flanks must fade when faced with a highly mobile enemy. These concepts are invalid on a modern battlefield where the US, in particular, is present

due to American multi-dimensional attack. Considerations of restricted movement are also less important to an enemy who can fly, if they also control the air space.”

“Extremely well-organized survey. Examples are thoughtfully chosen and clearly illustrate the principles intended. In trying to understand historical battles, I believe the attributes of tactical situations need to be understood in relation to terrain, to the correlation of forces, and above all, to the command and control capabilities of the opposing sides.”

APPENDIX B: REPORT OF SECOND SURVEY OF SUBJECT MATTER EXPERTS

Overview:

The purpose of the survey is to determine if there is a common agreement among subject matter experts (SMEs) of the validity of TIGER's determination of the similarity or dissimilarity of tactical situations. In this survey, SMEs were presented with two tactical situations taken from the West Point Atlas (Esposito, The West Point Atlas of American Wars, Volume 1 (1689-1900)) and (Esposito, The West Point Atlas of American Wars, Volume 2 (1900-1953)) that TIGER had previously classified as either very similar or very dissimilar and asked to agree or disagree with TIGER's classification.

IRB Approval:

The IRB ruled this survey exempt.

Subject Matter Experts:

Twelve Subject Matter Experts participated in the survey. They included:

- 7 Professional Wargame Designers
- Active duty and retired U. S. Army officers including:
 - Colonel (Ret.) USMC infantry 5 combat tours, 3 advisory tours
 - Maj. USA. (SE Core) Project Leader, TCM-Virtual Training
 - Officer at TRADOC (U. S. Army Training and Doctrine Command)
 - West Point; Warfighting Simulation Center
 - Instructor, Dept of Tactics Command & General Staff College
- Tactics Instructor at Kingston (Canadian equivalent of Ft. Leavenworth)
- Author of "The Art of Wargaming" and instructor at Annapolis.

The survey, as it appeared on the web, is presented below with the survey responses for each question immediately following.



Grouping tactical situations by attributes

First, thank you very much for making the time in your schedule to take this survey. We know that you are busy, but your input is vital to our research.

Second, and we cannot stress this enough, you are not being tested. There are no 'right' or 'wrong' answers in this survey.

Third, you can stop this survey at any point and return later to complete the survey where you left off.

Our Research

We theorize that tactical situations can be separated into meaningful categories by the use of algorithms that calculate the values of significant attributes and classify the tactical situations accordingly.

Our first survey (you can see the results [here](#); link opens in a new window) helped identify four important attributes: Anchored (or Unanchored flanks), Restricted Avenues of Attack, Restricted Avenues of Retreat and Interior (and Exterior) Lines.

This Survey:

The purpose of this survey is to determine if there is a common agreement among subject matter experts with the categories that our algorithms have created for historical tactical situations. We would also like to hear of any other attributes for categorization that you may suggest.

This survey is conducted as part of the doctoral research by D. Ezra Sidran, Department of Computer Science at the University of Iowa. To contact the survey author with questions or comments please send email to dsidran@cs.uiowa.edu. A link to our research papers on the subject of computational military reasoning is here: [papers](#) (link opens in a new window).

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[This online survey is powered by WebSurveyor.](#)



Grouping tactical situations by attributes

Attributes:

Our research entails identifying significant features of tactical situations so that they may be categorized. We use the term 'attributes' to describe these significant features that we will use to separate tactical situations into similar categories.

Our categorization (or 'clustering') algorithms currently use the following attributes:

- Anchored and Unanchored Flanks
- Interior Lines
- Restricted Avenues of Attack
- Restricted Avenues of Retreat
- Relative Elevation of Forces Weighted by Unit Type
- Force Strength Weighted by Unit Type

On each of the following pages we will show you two tactical situations that our algorithms have identified as either being similar or dissimilar and we will ask if you agree or disagree with the analysis.

This is a survey and we are asking your opinion; you are not being tested and there are no 'right' or 'wrong' answers.

After each question in the survey, as well as at the end of the survey, you will be asked to suggest other possible attributes.

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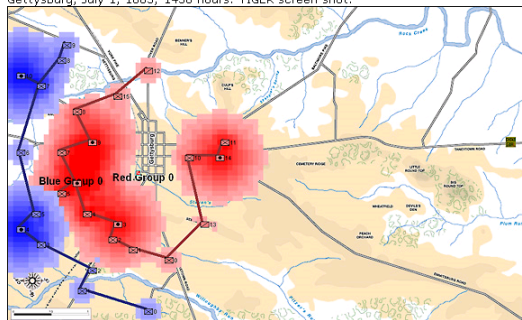


Grouping tactical situations by attributes

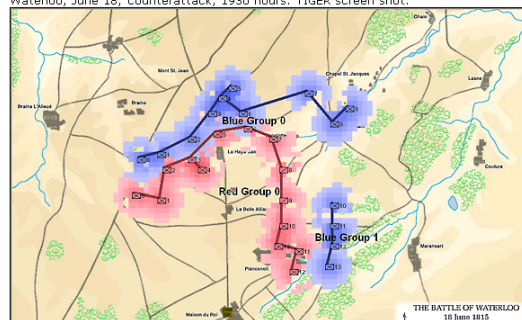
Gettysburg (Day 1, 1430 hours) & Waterloo (Anglo-Allied counterattack, 1930 hours)

Below are screen shots of two tactical situations that TIGER, our test program, *has identified as being similar*. In the right column are the list of attributes and values that resulted in this classification. At the bottom of this page you will be asked if you agree or disagree that these two tactical situations are similar and asked to suggest any other attributes that may be useful in identifying similar tactical situations.

Gettysburg, July 1, 1863; 1430 hours. TIGER screen shot.



Waterloo, June 18; counterattack, 1930 hours. TIGER screen shot.



Attribute evaluation:

	Interior Line Values
Gettysburg	-92,279
Waterloo	-94,884

These very similar negative values indicate that in both of these tactical situations REDFOR has similar strong interior lines.

	BLUEFOR Avenues of Attack
Gettysburg	7
Waterloo	7

In both tactical situations BLUEFOR has almost unrestricted avenues of attack.

	REDFOR Anchored Flank Value
Gettysburg	0
Waterloo	0.77

Neither REDFOR flank is anchored at Gettysburg, one REDFOR flank is anchored at Waterloo.

	REDFOR Avenues of Retreat
Gettysburg	7
Waterloo	8

In both tactical situations REDFOR has almost unrestricted avenues of retreat.

	Weighted Elevation (in meters) RED / BLUE
Gettysburg	104 / 142
Waterloo	60 / 63

In both tactical situations the ratio of RED / BLUE elevation is similar with BLUE having an advantage.

	Ratio of forces weighted RED / BLUE
Gettysburg	88 / 108
Waterloo	135 / 267

In both tactical situations the ratio of RED / BLUE troop strength is similar with BLUE having an advantage.

Do you feel that these two tactical situations (Gettysburg Day 1, 1430 hours and Waterloo, 1930 hours) are similar tactical situations?

- ☐ Yes
☐ No

If you answered 'Yes', do the attributes used, in your opinion, adequately capture the nature of the situation? Are there other additional features you would suggest that make these two tactical situations similar?

There is no limitation on the amount of text that you can enter in the box below.

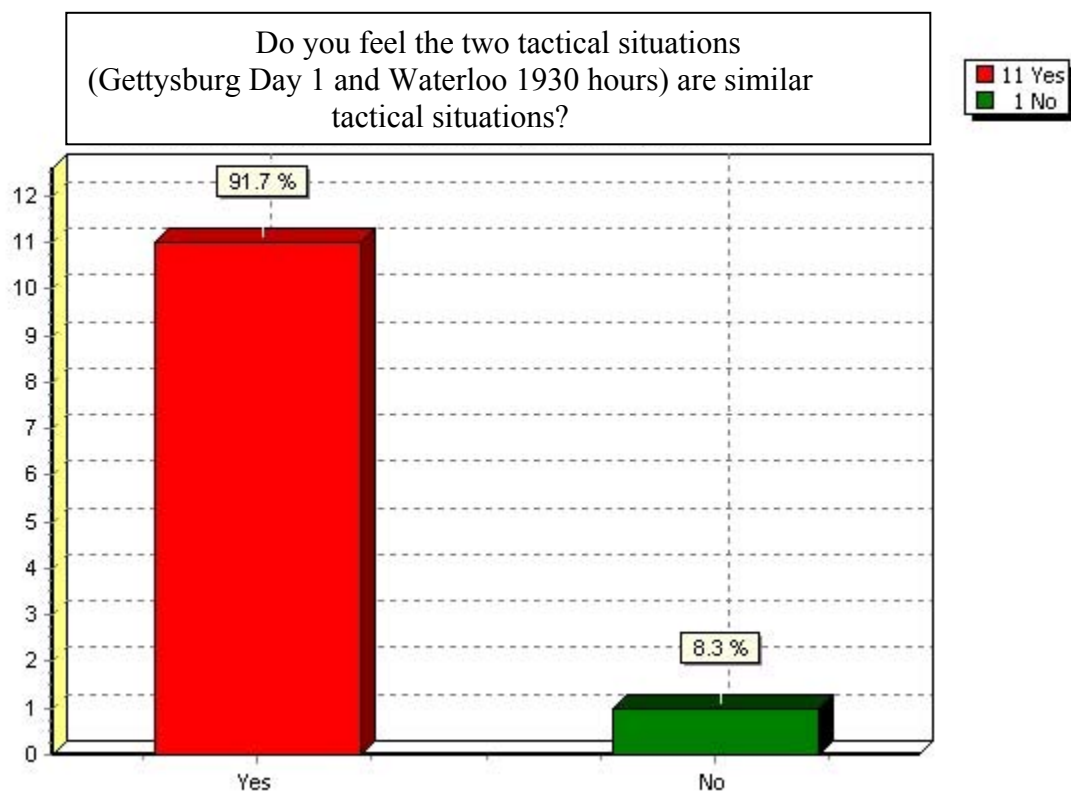
If you answered 'No', can you identify additional features that might be used to better distinguish the two tactical situations?

There is no limitation on the amount of text that you can enter in the box below.

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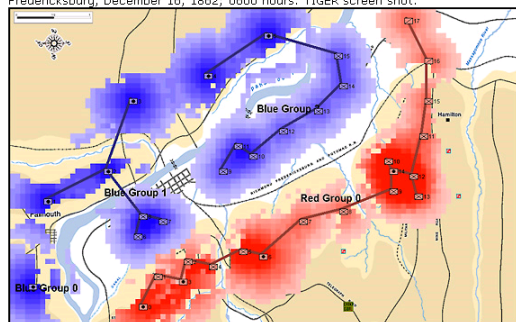


Grouping tactical situations by attributes

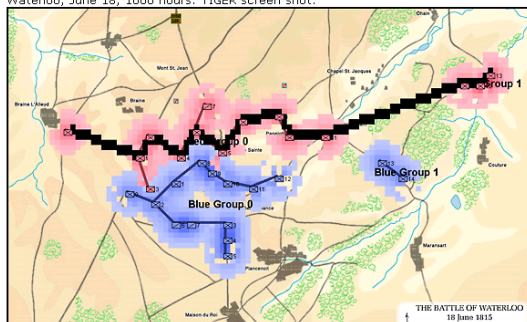
Fredericksburg (0600 hours) & Waterloo (1600 hours)

Below are screen shots of two tactical situations that TIGER, our test program, *has identified as being similar*. In the right column are the list of attributes and values that resulted in this classification. At the bottom of this page you will be asked if you agree or disagree that these two tactical situations are similar and asked to suggest any other attributes that may be useful in identifying similar tactical situations.

Fredericksburg, December 16, 1862; 0600 hours. TIGER screen shot.



Waterloo, June 18, 1600 hours. TIGER screen shot.



Attribute evaluation:

	Interior Line Values
Fredericksburg	133,451
Waterloo	139,848

These very similar positive values indicate that in both of these tactical situations REDFOR **does not** have the advantage of interior lines.

	BLUEFOR Avenues of Attack
Fredericksburg	8
Waterloo	8

In both tactical situations BLUEFOR has unrestricted avenues of attack.

	REDFOR Anchored Flank Value
Fredericksburg	1.0
Waterloo	0.29

Both REDFOR flanks are anchored at Fredericksburg, one REDFOR flank is weakly anchored at Waterloo.

	REDFOR Avenues of Retreat
Fredericksburg	7
Waterloo	7

In both tactical situations REDFOR has almost unrestricted avenues of retreat.

	Weighted Elevation (in meters) RED / BLUE
Fredericksburg	36 / 41
Waterloo	60 / 63

In both tactical situations the ratio of RED / BLUE elevation is similar with BLUE having a slight advantage.

	Ratio of forces weighted RED / BLUE
Fredericksburg	72.5 / 114
Waterloo	135 / 267

In both tactical situations the ratio of RED / BLUE troop strength is similar with BLUE having an advantage.

Do you feel that these two tactical situations (Fredericksburg, 0600 hours and Waterloo, 1600 hours) are similar tactical situations?

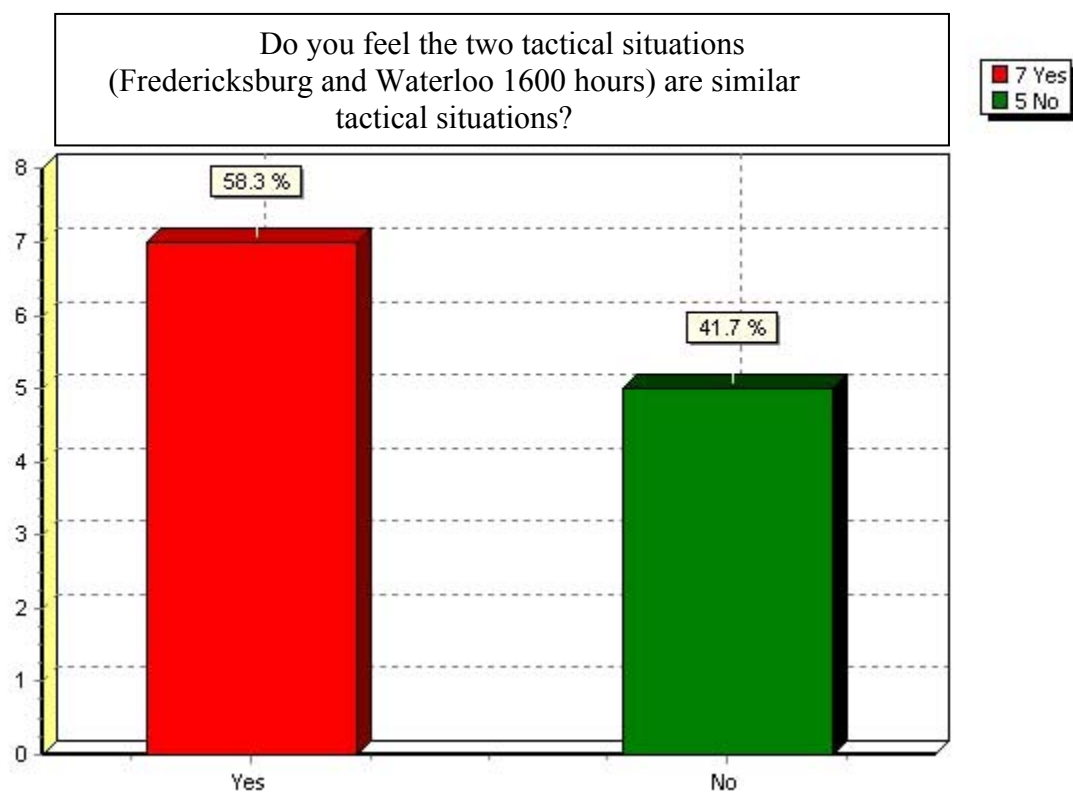
- ☐ Yes
☐ No

If you answered 'Yes', do the attributes used, in your opinion, adequately capture the nature of the situation? Are there other additional features you would suggest that make these two tactical situations similar?

There is no limitation on the amount of text that you can enter in the box below.

If you answered 'No', can you identify additional features that might be used to better distinguish the two tactical situations?

There is no limitation on the amount of text that you can enter in the box below.



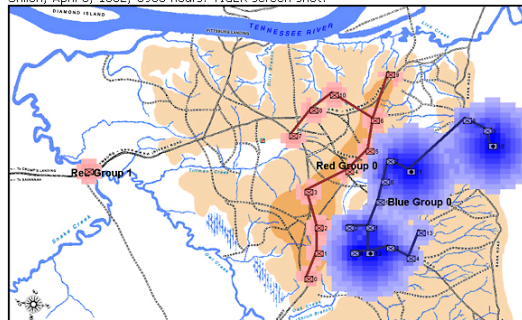


Grouping tactical situations by attributes

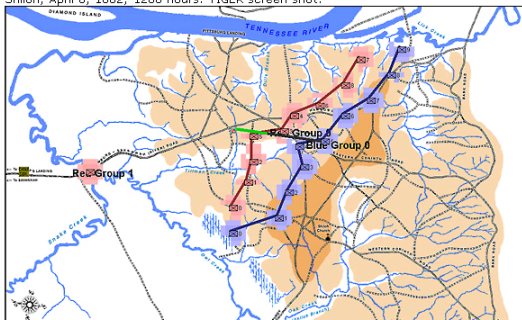
Shiloh (Day 1, 0900 hours) & Shiloh (Day 1, 1200 hours)

Below are screen shots of two tactical situations that TIGER, our test program, *has identified as being similar*. In the right column are the list of attributes and values that resulted in this classification. At the bottom of this page you will be asked if you agree or disagree that these two tactical situations are similar and asked to suggest any other attributes that may be useful in identifying similar tactical situations.

Shiloh, April 6, 1862; 0900 hours. TIGER screen shot.



Shiloh, April 6, 1862; 1200 hours. TIGER screen shot.



Attribute evaluation:

	Interior Line Values
Shiloh 0900	34,977
Shiloh 1200	12,418

These relatively small positive values indicate that in both of these tactical situations REDFOR does not have interior lines.

	BLUEFOR Avenues of Attack
Shiloh 0900	6
Shiloh 1200	6

In both tactical situations BLUEFOR has mostly unrestricted avenues of attack.

	REDFOR Anchored Flank Value
Shiloh 0900	0
Shiloh 1200	0

Neither REDFOR flank is anchored in both tactical situations.

	REDFOR Avenues of Retreat
Shiloh 0900	2
Shiloh 1200	2

In both tactical situations REDFOR is restricted to 2 avenues of retreat.

	Weighted Elevation (in meters) RED / BLUE
Shiloh 0900	24 / 30
Shiloh 1200	15 / 22

In both tactical situations the ratio of RED / BLUE elevation is similar with BLUE having an advantage.

	Ratio of forces weighted RED / BLUE
Shiloh 0900	62 / 40
Shiloh 1200	62 / 40

In both tactical situations the ratio of RED / BLUE troop strength is identical with RED having an advantage.

Do you feel that these two tactical situations (Shiloh Day 1, 0900 hours and Shiloh Day 1, 1200 hours) are similar tactical situations?

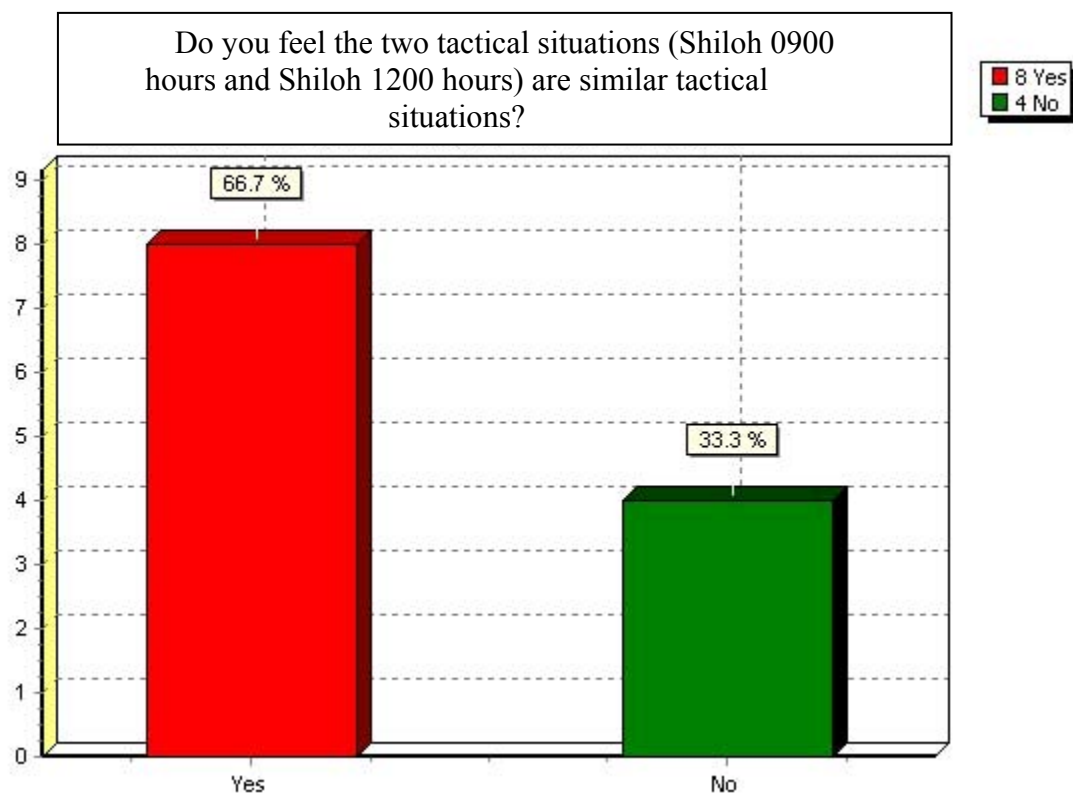
- ☐ Yes
☐ No

If you answered 'Yes', do the attributes used, in your opinion, adequately capture the nature of the situation? Are there other additional features you would suggest that make these two tactical situations similar?

There is no limitation on the amount of text that you can enter in the box below.

If you answered 'No', can you identify additional features that might be used to better distinguish the two tactical situations?

There is no limitation on the amount of text that you can enter in the box below.



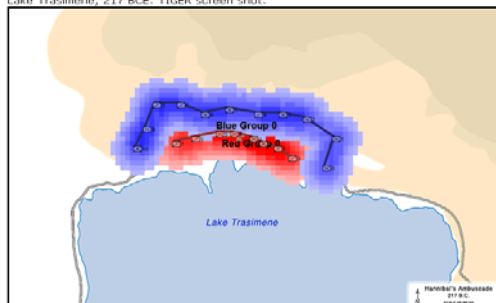


Grouping tactical situations by attributes

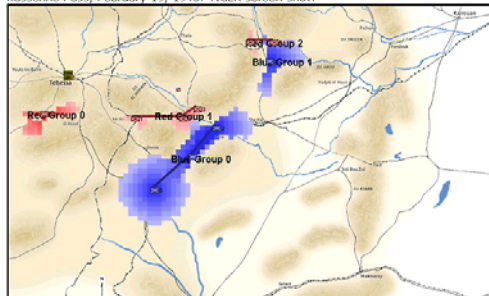
Lake Trasimene (217 BCE) & Kasserine Pass (February 19, 1943)

Below are screen shots of two tactical situations that TIGER, our test program, *has identified as being very dissimilar*. In the right column are the list of attributes and values that resulted in this classification. At the bottom of this page you will be asked if you agree or disagree that these two tactical situations are dissimilar and asked to suggest any other attributes that may be useful in differentiating tactical situations.

Lake Trasimene, 217 BCE. TIGER screen shot.



Kasserine Pass, February 19, 1943. TIGER screen shot.



Attribute evaluation:

	Interior Line Values
Lake Trasimene	-115,079
Kasserine Pass (2/19/43)	262,357

The negative value for Lake Trasimene indicates that REDFOR clearly has interior lines while the large positive number for Kasserine Pass indicates that REDFOR **does not** have interior lines.

	BLUEFOR Avenues of Attack
Lake Trasimene	6
Kasserine Pass (2/19/43)	5

In both tactical situations BLUEFOR has mostly unrestricted avenues of attack.

	REDFOR Anchored Flank Value
Lake Trasimene	1
Kasserine Pass (2/19/43)	0

At Lake Trasimene both REDFOR flanks are anchored, while at Kasserine Pass neither REDFOR flank is anchored.

	REDFOR Avenues of Retreat
Lake Trasimene	1
Kasserine Pass (2/19/43)	7

At Lake Trasimene REDFOR's avenue of retreat is severely restricted (having only one escape route), while at Kasserine Pass REDFOR has almost unrestricted avenues of retreat.

	Weighted Elevation (in meters) RED / BLUE
Lake Trasimene	1 / 43
Kasserine Pass (2/19/43)	97 / 214

There is a dissimilarity in the ratio of RED / BLUE elevation, however BLUE does have an advantage in both tactical situations.

	Ratio of forces weighted RED / BLUE
Lake Trasimene	34 / 50
Kasserine Pass (2/19/43)	30 / 22

At Lake Trasimene, BLUEFOR has a weighted strength advantage while at Kasserine Pass REDFOR has the strength advantage.

Do you feel that these two tactical situations (Lake Trasimene, 217 BCE and Kasserine Pass, February 19, 1943) are very dissimilar tactical situations?

- ☐ Yes
☐ No

If you answered 'Yes', do the attributes used, in your opinion, adequately capture the nature of the situation? Are there other additional features you would suggest that make these two tactical situations very dissimilar?

There is no limitation on the amount of text that you can enter in the box below.

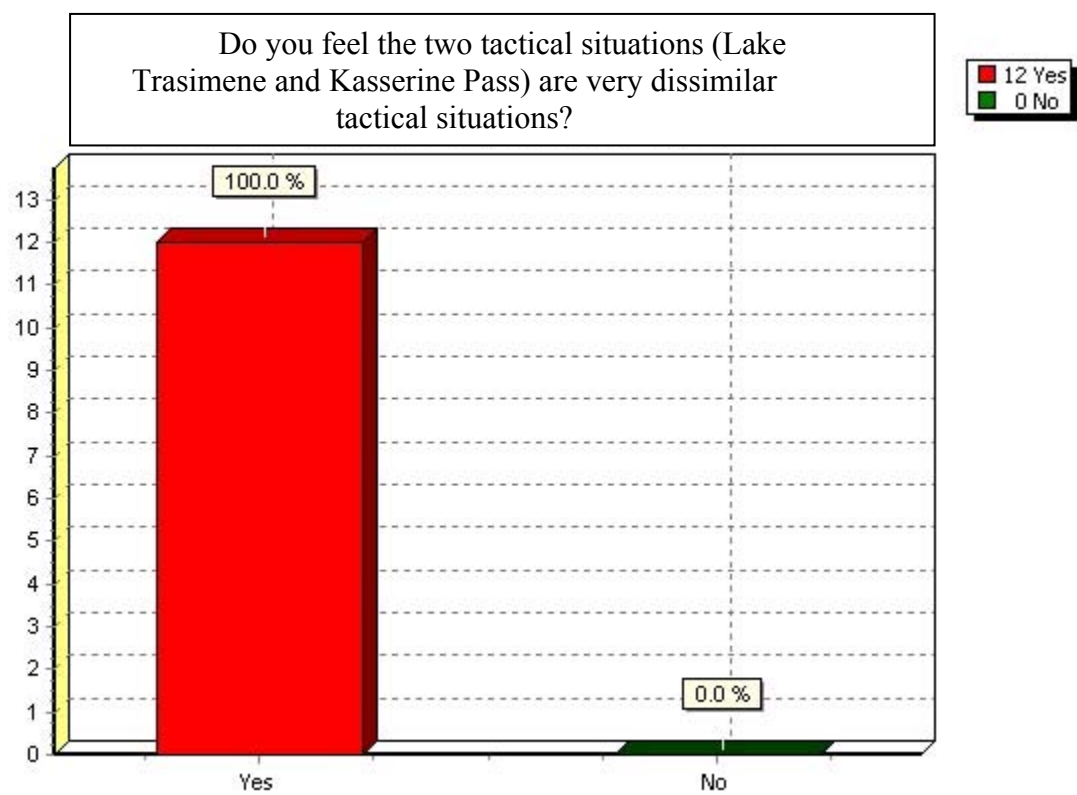
If you answered 'No', can you identify additional features that might be used to better distinguish the two tactical situations?

There is no limitation on the amount of text that you can enter in the box below.

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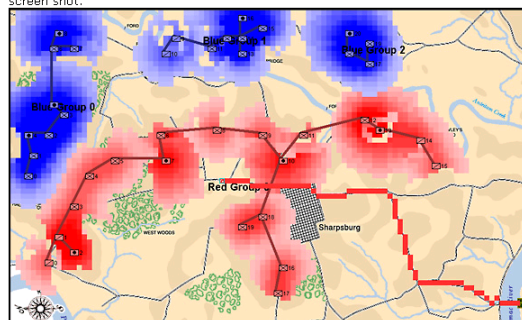


Grouping tactical situations by attributes

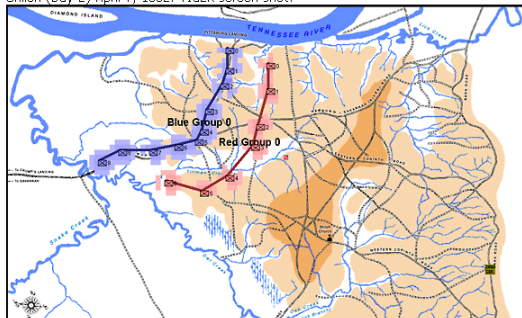
Antietam (September 17, 1862) & Shiloh (Day 2, April 7, 1862)

Below are screen shots of two tactical situations that TIGER, our test program, *has identified as being very dissimilar*. In the right column are the list of attributes and values that resulted in this classification. At the bottom of this page you will be asked if you agree or disagree that these two tactical situations are dissimilar and asked to suggest any other attributes that may be useful in differentiating tactical situations.

Antietam, September 17, 1862. REDFOR's one avenue of retreat shown in red. TIGER screen shot.



Shiloh (Day 2) April 7, 1862. TIGER screen shot.



Attribute evaluation:

	Interior Line Values
Antietam	-54,097
Shiloh (Day 2)	34,188

The negative value for Antietam indicates that REDFOR has good interior lines while the positive number for Shiloh (Day 2) indicates that REDFOR **does not** have interior lines.

	BLUEFOR Avenues of Attack
Antietam	8
Shiloh (Day 2)	6

At Antietam, BLUEFOR has completely unrestricted avenues of attack while at Shiloh, BLUEFOR has partially unrestricted avenues of attack.

	REDFOR Anchored Flank Value
Antietam	1
Shiloh (Day 2)	0

At Antietam both REDFOR flanks are anchored, while at Shiloh (Day 2) neither REDFOR flank is anchored.

	REDFOR Avenues of Retreat
Antietam	1
Shiloh (Day 2)	5

At Antietam REDFOR's avenue of retreat is severely restricted (having only one escape route), while at Shiloh (Day 2) REDFOR has almost unrestricted avenues of retreat.

	Weighted Elevation (in meters) RED / BLUE
Antietam	80 / 79
Shiloh (Day 2)	28 / 14

There is a dissimilarity in the ratio of RED / BLUE elevation.

	Ratio of forces weighted RED / BLUE
Antietam	257 / 297
Shiloh (Day 2)	40 / 62

The ratios are similar for both tactical situations.

Do you feel that these two tactical situations (Antietam, September 17, 1862 and Shiloh, April 7, 1862) are very dissimilar tactical situations?

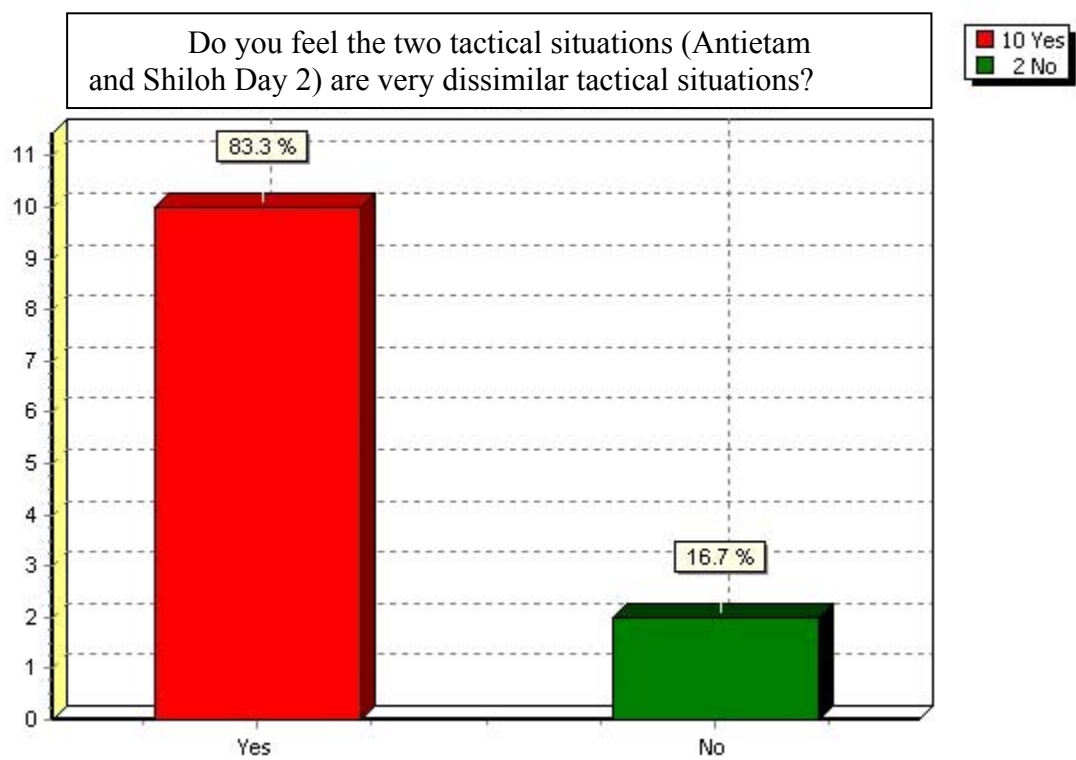
- ☐ Yes
☐ No

If you answered 'Yes', do the attributes used, in your opinion, adequately capture the nature of the situation? Are there other additional features you would suggest that make these two tactical situations very dissimilar?

There is no limitation on the amount of text that you can enter in the box below.

If you answered 'No', can you identify additional features that might be used to better distinguish the two tactical situations?

There is no limitation on the amount of text that you can enter in the box below.



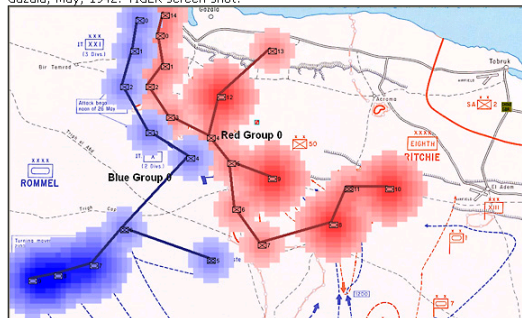


Grouping tactical situations by attributes

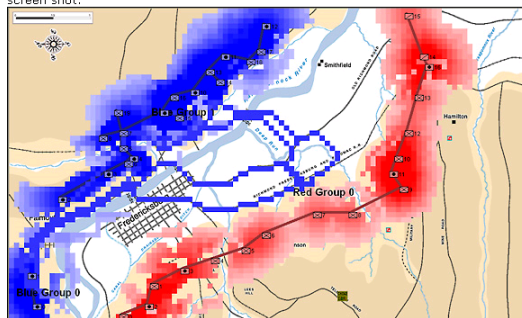
Gazala (May 27, 1942) & Fredericksburg (December 10, 1862)

Below are screen shots of two tactical situations that TIGER, our test program, *has identified as being very dissimilar*. In the right column are the list of attributes and values that resulted in this classification. At the bottom of this page you will be asked if you agree or disagree that these two tactical situations are dissimilar and asked to suggest any other attributes that may be useful in differentiating tactical situations.

Gazala, May, 1942. TIGER screen shot.



Fredericksburg, December 10, 1862. Note: Red lines are avenues of attack. TIGER screen shot.



Attribute evaluation:

	Interior Line Values
Gazala	-92,270
Fredericksburg	35,625

The negative value for Gazala indicates that REDFOR has interior lines while the positive number for Fredericksburg indicates that REDFOR **does not** have interior lines.

	BLUEFOR Avenues of Attack
Gazala	8
Fredericksburg	4

At Gazala, BLUEFOR has completely unrestricted avenues of attack while at Fredericksburg, BLUEFOR has restricted avenues of attack (note the thick blue lines over the pontoon bridges).

	REDFOR Anchored Flank Value
Gazala	0.67
Fredericksburg	1

At Gazala one REDFOR flank is anchored, while at Fredericksburg both REDFOR flanks are anchored.

	REDFOR Avenues of Retreat
Gazala	8
Fredericksburg	8

Both tactical situations have unlimited REDFOR avenues of retreat.

	Weighted Elevation (in meters) RED / BLUE
Gazala	13 / 25
Fredericksburg	36 / 54

There is a similarity in the ratio of RED / BLUE elevation.

	Ratio of forces weighted RED / BLUE
Gazala	175 / 80
Fredericksburg	72.5 / 114

The ratios are dissimilar for the two tactical situations with REDFOR having an advantage at Gazala and BLUEFOR having an advantage at Fredericksburg.

Do you feel that these two tactical situations (Gazala, May 27, 1942 and Fredericksburg, December 10, 1862) **are very dissimilar tactical situations**?

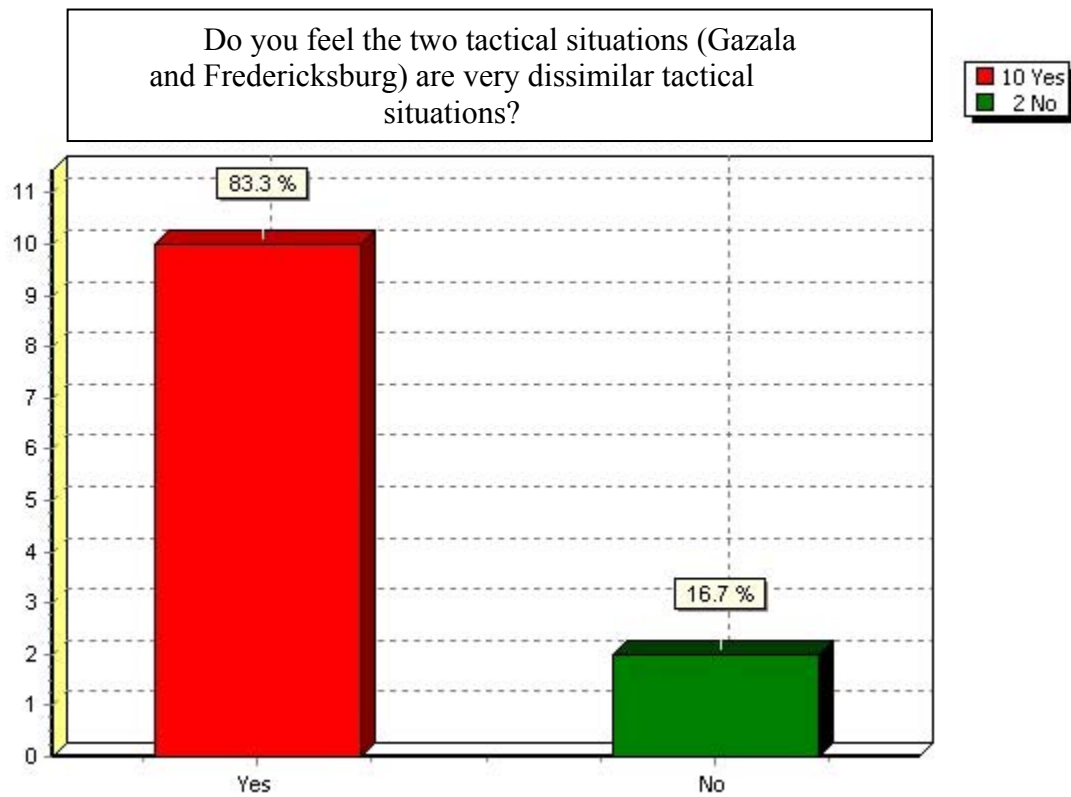
- ☐ Yes
☐ No

If you answered 'Yes', do the attributes used, in your opinion, adequately capture the nature of the situation? Are there other additional features you would suggest that make these two tactical situations very dissimilar?

There is no limitation on the amount of text that you can enter in the box below.

If you answered 'No', can you identify additional features that might be used to better distinguish the two tactical situations?

There is no limitation on the amount of text that you can enter in the box below.



The SMEs were encouraged to write ‘free-form’ comments about the questions and the survey in general (the comments, and indeed, the SME’s specific survey responses, were anonymous). Some of the more interesting comments about the overall survey appear below:

“This is interesting. I am an SME who is NOT familiar with the ACW battles. I find that I must generally agree with the programme assessment of variables as presented BUT my knowledge of Waterloo alerted me to the possibility that the programme may not be considering decisive factors, especially those that concern attritional exchange mechanisms.”

“This is a lot of fun for me. You may be on to something here that Homeland Defense folks could use. Most modeling and simulation applications look at the kinetic side of things. A few look at soft power but I’m not aware of one that looks at these tactical parameters.”

“It would be interesting to know how you arrived at those particular values to weigh each scenario. I would venture to say that there are a number of things, though less ‘concrete’, which would alter the differences between each scenario a great deal, such as troop morale, leader influence, past history of the leaders involved, and motivation of each side (local militia v. invading military). Just curious as to whether TIGER will take these things into account and add/subtract values accordingly.”

“Interesting comparisons. I must admit that I had some trouble with the gross differences between fights from fundamentally different technological eras. All combats share common features but sometimes the nature of the technology imposes fundamentally different conditions on the possibilities available to the contending forces. When fundamentally different military systems engage, either

in the same fight (Isandlwana) or when comparing different fights, the systemic differences seem to account for critical elements of the characters of those fights. Your factors, which are largely physical and have to do mainly with the field of battle, do not seem to account for the other critical elements, such as psychology and terrain effects on the ability of the combatants to employ their weapons in effectively lethal ways (such as cover and concealment).”

“This is really excellent work. I hope you will be able to generate powerful predictive results from a limited number of variables in a formal model, but it is important to remember that battle is a human activity, and war is still the domain of chaos.”

APPENDIX C: REPORT OF THIRD SURVEY OF SUBJECT MATTER EXPERTS

Overview:

This was the final survey of our study and its purpose was to validate both hypotheses:

Hypothesis 1: There is agreement among military experts that tactical situations exhibit certain features (or attributes) and that these features can be used by SMEs to group tactical situations by similarity.

Hypothesis 2: The best match (by TIGER of a new scenario to a scenario from its historical database) predicts what the experts would choose.

In this survey we created five hypothetical tactical situations and had TIGER classify them with 20 historical tactical situations taken from the West Point Atlas (Esposito, The West Point Atlas of American Wars, Volume 1 (1689-1900)) and (Esposito, The West Point Atlas of American Wars, Volume 2 (1900-1953)) (see Appendix D). We then presented the SMEs with the hypothetical tactical situation and one historical tactical situation that appeared within the same ‘cluster’ or ‘partition’ as the hypothetical tactical situation and one tactical situation that did not appear within the same cluster. The SMEs were then given the choice of historical situation ‘A’, historical situation ‘B’ or ‘neither’.

IRB Approval:

The IRB ruled this survey exempt.

Subject Matter Experts:

Twenty-three Subject Matter Experts participated in the survey (we are especially indebted to Col. John Surdu who helped recruit active-duty field grade officers with tactical experience). They included:

The survey, as it appeared on the web, is presented below with the survey responses for each question immediately following.

SME survey to test TIGER's grouping of similar tactical situations.



First, thank you very much for making the time in your schedule to take this survey. We know that you are busy, but your input is vital to our research.

Second, and we cannot stress this enough, you are not being tested. There are no 'right' or 'wrong' answers in this survey. Actually, we are testing TIGER, to see if its 'answers' match the answers of Subject Matter Experts (SMEs) like you.

Third, you can stop this survey at any point and return later to complete the survey where you left off.

Our Research

We have created TIGER, a test program, that analyzes tactical situations, classifies them and then places them into groups based on similarity of certain attributes.

This Survey:

The purpose of this survey is to test TIGER's classification of some hypothetical tactical situations and compare its results to the answers of Subject Matter Experts (SMEs), like you.

In the following screens you will be shown a 'hypothetical' tactical situation and two historical tactical situations taken from the West Point Atlas of American Wars. You will then be asked if, in your opinion, the 'hypothetical' tactical situation is more like historical situation 'A', historical situation 'B' or neither of the historical situations.

We would also like you to "check your historical knowledge at the door." That is to say, even though you know, historically, what happened in these tactical situations, please try to look at the historical situations as a 'moment frozen in time' and try not to be influenced by what you know actually happened.

In all scenarios REDFOR is defending and BLUEFOR is attacking.

This survey is conducted as part of the doctoral research by D. Ezra Sidran, Department of Computer Science at the University of Iowa. To contact the survey author with questions or comments please send email to dsidran@cs.uiowa.edu. A link to our research papers on the subject of computational military reasoning is here: [papers](#) (link opens in a new window).

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SME survey to test TIGER's grouping of similar tactical situations.

Survey Question #1:

Please look at the hypothetical tactical situation below and compare it to the two historical situations labeled 'A' and 'B'. In all scenarios, a defeated REDFOR will retreat towards the Red Star in the Green Square on the map. All images are TIGER screen captures.

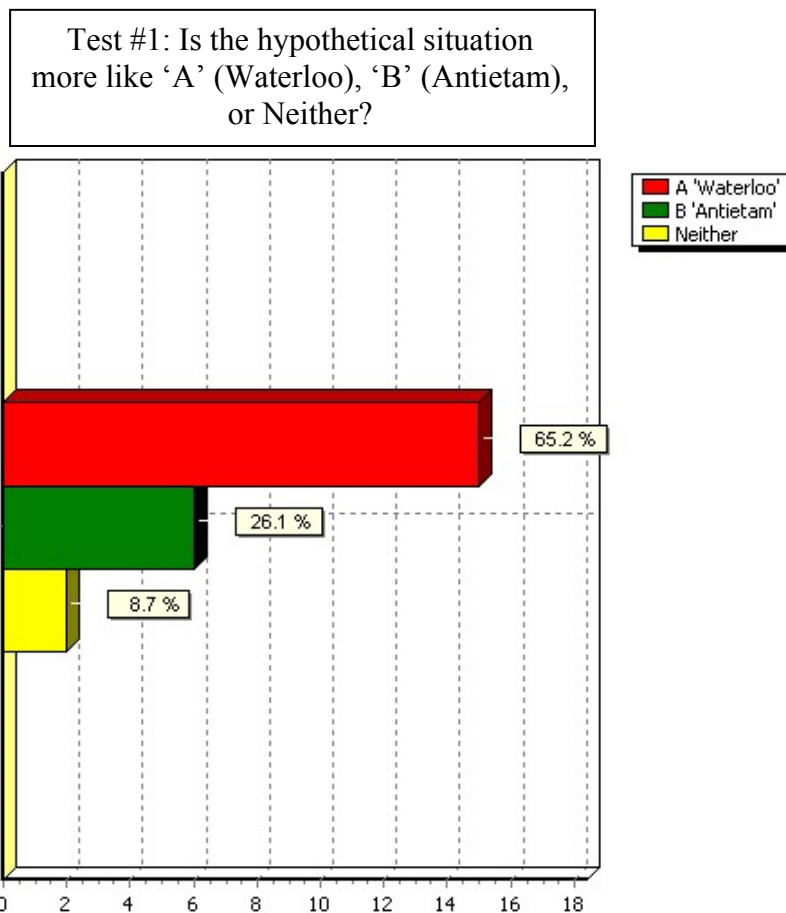
In your opinion is the hypothetical tactical situation more like 'A' or 'B'?

	Hypothetical tactical situation #1 If defeated, REDFOR will retreat to the west. The weighted ratio (strength * unit type) of REDFOR / BLUEFOR = 0.780742 (i.e. BLUEFOR has the superior force). The slope of the attack is = 1.266667 (i.e. BLUEFOR is attacking uphill).
	Tactical Situation 'A', the battle of Waterloo (about 1000 hours). If defeated, REDFOR will retreat to the north. The weighted ratio (strength * unit type) of REDFOR / BLUEFOR = 0.531510 (i.e. BLUEFOR has the superior force). The slope of the attack is = 1.109091 (i.e. BLUEFOR is attacking slightly uphill).
	Tactical Situation 'B', the battle of Antietam Note: there is a ford in the lower right-hand corner of the map that crosses the Potomac River. If defeated, REDFOR will retreat across the Potomac, using the ford, to the lower right-hand corner of the map. The weighted ratio (strength * unit type) of REDFOR / BLUEFOR = 0.520211 (i.e. BLUEFOR has the superior force). The slope of the attack is = 1.058824 (i.e. BLUEFOR is attacking slightly uphill).

A 'Waterloo' B 'Antietam' Neither

Is the hypothetical tactical situation (above) more like: ☐ ☒ ☐

If you have any comments, please use the space below to enter text.
There is no limitation on the amount of text that you can enter in the box below.





SME survey to test TIGER's grouping of similar tactical situations.

Survey Question #2:

Please look at the hypothetical tactical situation below and compare it to the two historical situations labeled 'A' and 'B'. In all scenarios, a defeated REDFOR will retreat towards the Red Star in the Green Square on the map. All images are TIGER screen captures.

In your opinion is the hypothetical tactical situation more like 'A' or 'B'?

	Hypothetical tactical situation #2. If defeated, REDFOR will retreat to the north. The weighted ratio (strength * unit type) of REDFOR / BLUEFOR = 0.392949 (i.e. BLUEFOR has the superior force). The slope of the attack is = 1.888889 (i.e. BLUEFOR is attacking uphill).
--	---

	Tactical Situation 'A', Kasserine Pass, February 14, 1943. If defeated, REDFOR will retreat to the west. The weighted ratio (strength * unit type) of REDFOR / BLUEFOR = 0.395032 (i.e. BLUEFOR has the superior force). The slope of the attack is = 1.097561 (i.e. BLUEFOR is attacking slightly uphill).
--	--

	Tactical Situation 'B', the battle of Gettysburg, Day 1. If defeated, REDFOR will retreat to the right of the map. The weighted ratio (strength * unit type) of REDFOR / BLUEFOR = 1.174957 (i.e. REDFOR has the superior force). The slope of the attack is = 0.914438 (i.e. BLUEFOR is attacking slightly downhill).
--	---

A 'Kasserine Pass' B 'Gettysburg' Neither

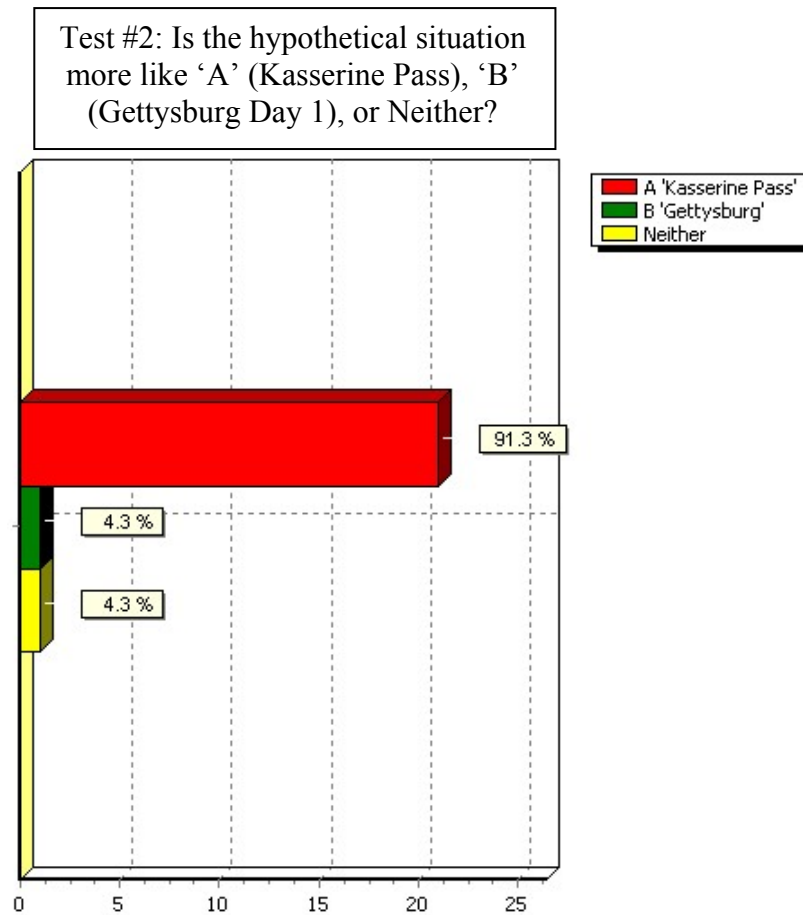
Is the hypothetical tactical situation (above) more like: ☐ ☒ ☐

If you have any comments, please use the space below to enter text.
There is no limitation on the amount of text that you can enter in the box below.

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SME survey to test TIGER's grouping of similar tactical situations.

Survey Question #3:

Please look at the hypothetical tactical situation below and compare it to the two historical situations labeled 'A' and 'B'. In all scenarios, a defeated REDFOR will retreat towards the Red Star in the Green Square on the map. All images are TIGER screen captures.

In your opinion is the hypothetical tactical situation more like 'A' or 'B'?

	Hypothetical tactical situation #3 If defeated, REDFOR will retreat to the north. The weighted ratio (strength * unit type) of REDFOR / BLUEFOR = 1.360255 (i.e. REDFOR has the superior force). The slope of the attack is = 1.909091 (i.e. BLUEFOR is attacking uphill).
	Tactical Situation 'A', the battle of Gettysburg, Day 2. If defeated, REDFOR will retreat to the right of the map. The weighted ratio (strength * unit type) of REDFOR / BLUEFOR = 1.388581 (i.e. REDFOR has the superior force). The slope of the attack is = 1.263158 (i.e. BLUEFOR is attacking uphill).
	Tactical Situation 'B', the battle of Shiloh, Day 1, about 0900 hours. If defeated, REDFOR will retreat to the left-hand edge of the map. The weighted ratio (strength * unit type) of REDFOR / BLUEFOR = 0.859028 (i.e. BLUEFOR has the superior force). The slope of the attack is = 1.361111 (i.e. BLUEFOR is attacking uphill).

A 'Gettysburg' B 'Shiloh' Neither

Is the hypothetical tactical situation (above) more like:

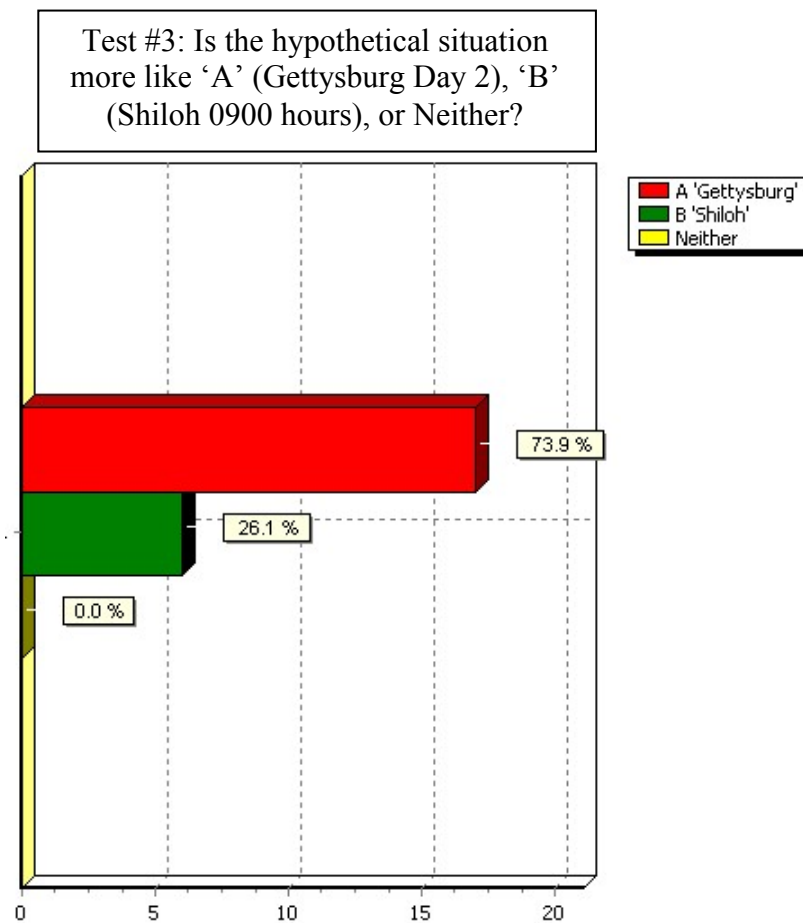
☒ A ☐ B ☐ Neither

If you have any comments, please use the space below to enter text.
There is no limitation on the amount of text that you can enter in the box below.

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SME survey to test TIGER's grouping of similar tactical situations.

Survey Question #4:

Please look at the hypothetical tactical situation below and compare it to the two historical situations labeled 'A' and 'B'. In all scenarios, a defeated REDFOR will retreat towards the Red Star in the Green Square on the map. All images are TIGER screen captures.

In your opinion is the hypothetical tactical situation more like 'A' or 'B'?

	Hypothetical tactical situation #4 If defeated, REDFOR will retreat to the west. The weighted ratio (strength * unit type) of REDFOR / BLUEFOR = 0.848140 (i.e. BLUEFOR has the superior force). The slope of the attack is = 2.363636 (i.e. BLUEFOR is attacking uphill).
	Tactical Situation 'A', the battle of Gettysburg, Day 2. If defeated, REDFOR will retreat to the right of the map. The weighted ratio (strength * unit type) of REDFOR / BLUEFOR = 1.388581 (i.e. REDFOR has the superior force). The slope of the attack is = 1.263158 (i.e. BLUEFOR is attacking uphill).
	Tactical Situation 'B', the battle of Fredericksburg. If defeated, REDFOR will retreat to the lower-right. The weighted ratio (strength * unit type) of REDFOR / BLUEFOR = 0.702763 (i.e. BLUEFOR has the superior force). The slope of the attack is = 3.833333 (i.e. BLUEFOR is attacking uphill).

A 'Gettysburg' B 'Fredericksburg' Neither

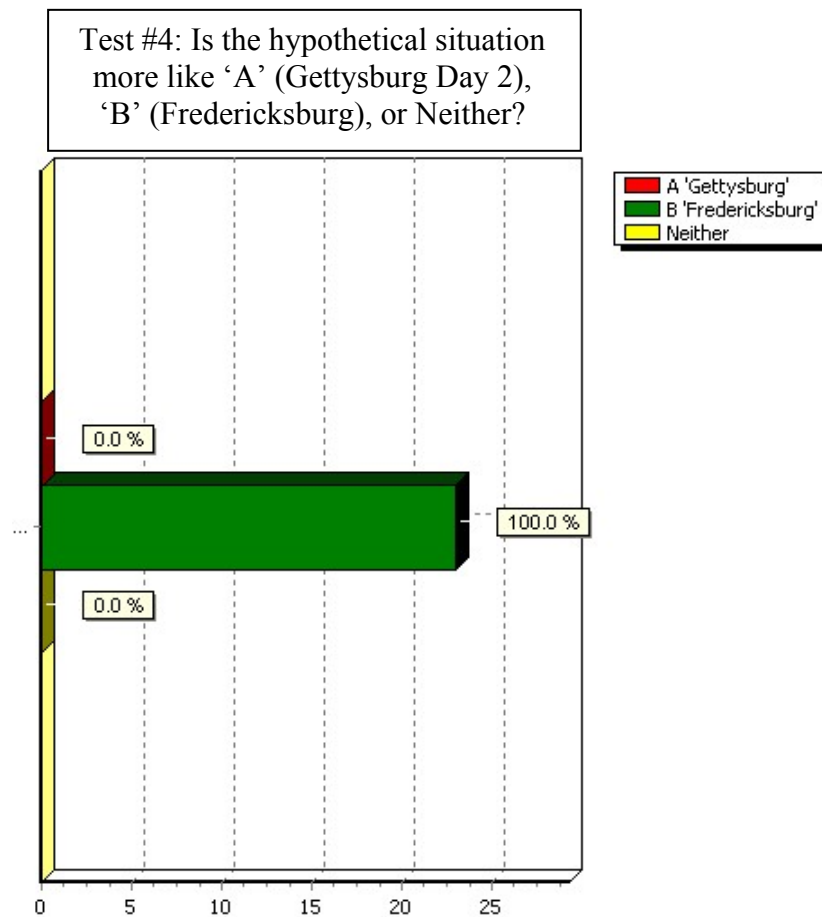
Is the hypothetical tactical situation (above) more like: ☐ ☒ ☐

If you have any comments, please use the space below to enter text.
There is no limitation on the amount of text that you can enter in the box below.

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SME survey to test TIGER's grouping of similar tactical situations.

Survey Question #5:

Please look at the hypothetical tactical situation below and compare it to the two historical situations labeled 'A' and 'B'. In all scenarios, a defeated REDFOR will retreat towards the Red Star in the Green Square on the map. All images are TIGER screen captures.

In your opinion is the hypothetical tactical situation more like 'A' or 'B'?

	Hypothetical tactical situation #5 If defeated, REDFOR will retreat to the east across the river. The weighted ratio (strength * unit type) of REDFOR / BLUEFOR = 0.863946 (i.e. BLUEFOR has the superior force). The slope of the attack is = 0.000260 (i.e. almost level).
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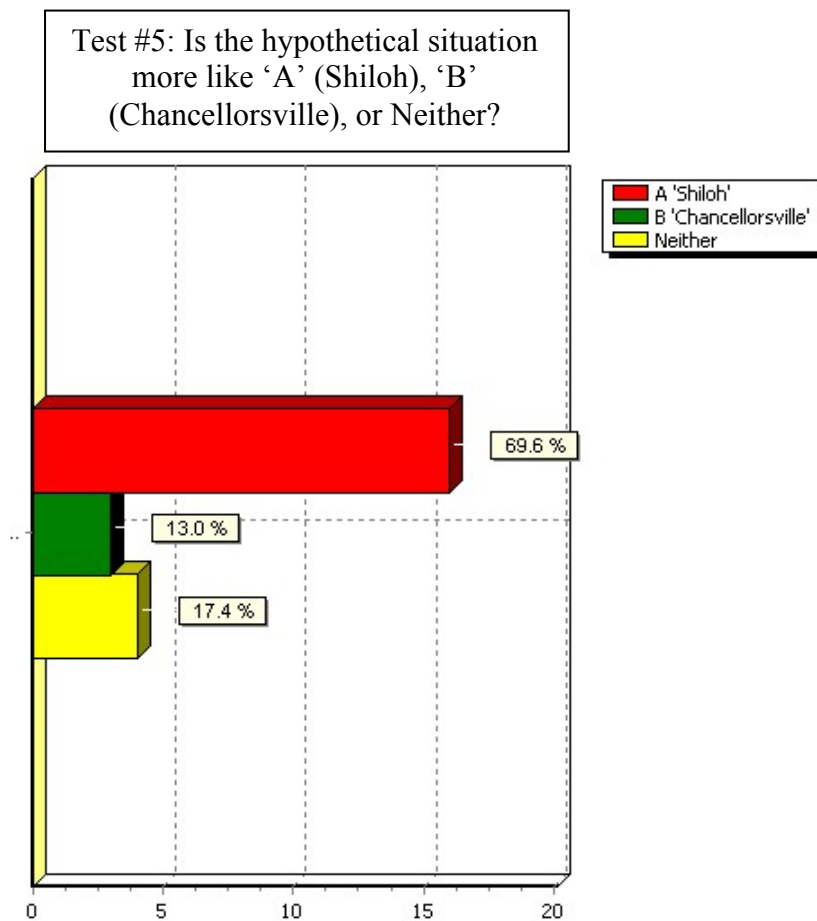
	Tactical Situation 'A', the battle of Shiloh, Day 1 about 0900 hours. If defeated, REDFOR will retreat to the left side of the map across the river. The weighted ratio (strength * unit type) of REDFOR / BLUEFOR = 0.85902 (i.e. BLUEFOR has the superior force). The slope of the attack is = 1.361111 (i.e. BLUEFOR is attacking uphill).
--	--

	Tactical Situation 'B', the battle of Chancellorsville, May 2. If defeated, REDFOR will retreat to the north. The weighted ratio (strength * unit type) of REDFOR / BLUEFOR = 1.76600 (i.e. REDFOR has the superior force). The slope of the attack is = 41.333332 (i.e. BLUEFOR is attacking uphill).
--	---

A 'Shiloh' B 'Chancellorsville' Neither

Is the hypothetical tactical situation (above) more like: ☒ ☐ ☐

If you have any comments, please use the space below to enter text. There is no limitation on the amount of text that you can enter in the box below.





SME survey to test TIGER's grouping of similar tactical situations.

Please use the space below to enter any comments or questions about this survey. There is no limit on the amount of text that you can enter.

If you have any other comments or would like to send an email: dsidran@cs.uiowa.edu.

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APPENDIX D: TIGER CONSTRUCTED CLASSIFICATION TREE OF 25 TACTICAL SITUATIONS

We present here a detailed view of the hierarchal classification tree (with TIGER screen captures) that TIGER produced over twenty-five tactical situations.

TIGER created ten clusters, or ‘partitions’ (Gennari and Langley) from the instances. We believe that certain observations can be made of the clusters:

The cluster C_1 contains two tactical situations that both have restricted avenues of attack caused by armor traveling through narrow mountainous passes. These passes also partially create restricted avenues of retreat. REDFOR does not have anchored flanks.

The cluster C_3 contains four tactical situations that all possess the common attributes of a severely restricted avenue of retreat for REDFOR, anchored flanks for REDFOR and interior lines for REDFOR.

The cluster C_{11} contains three tactical situations that all possess the common attributes of restricted avenues of approach for BLUEFOR and anchored flanks for REDFOR.

The cluster C_{23} contains four tactical situations that all possess the common attributes of interior lines for REDFOR and one anchored flank for REDFOR.

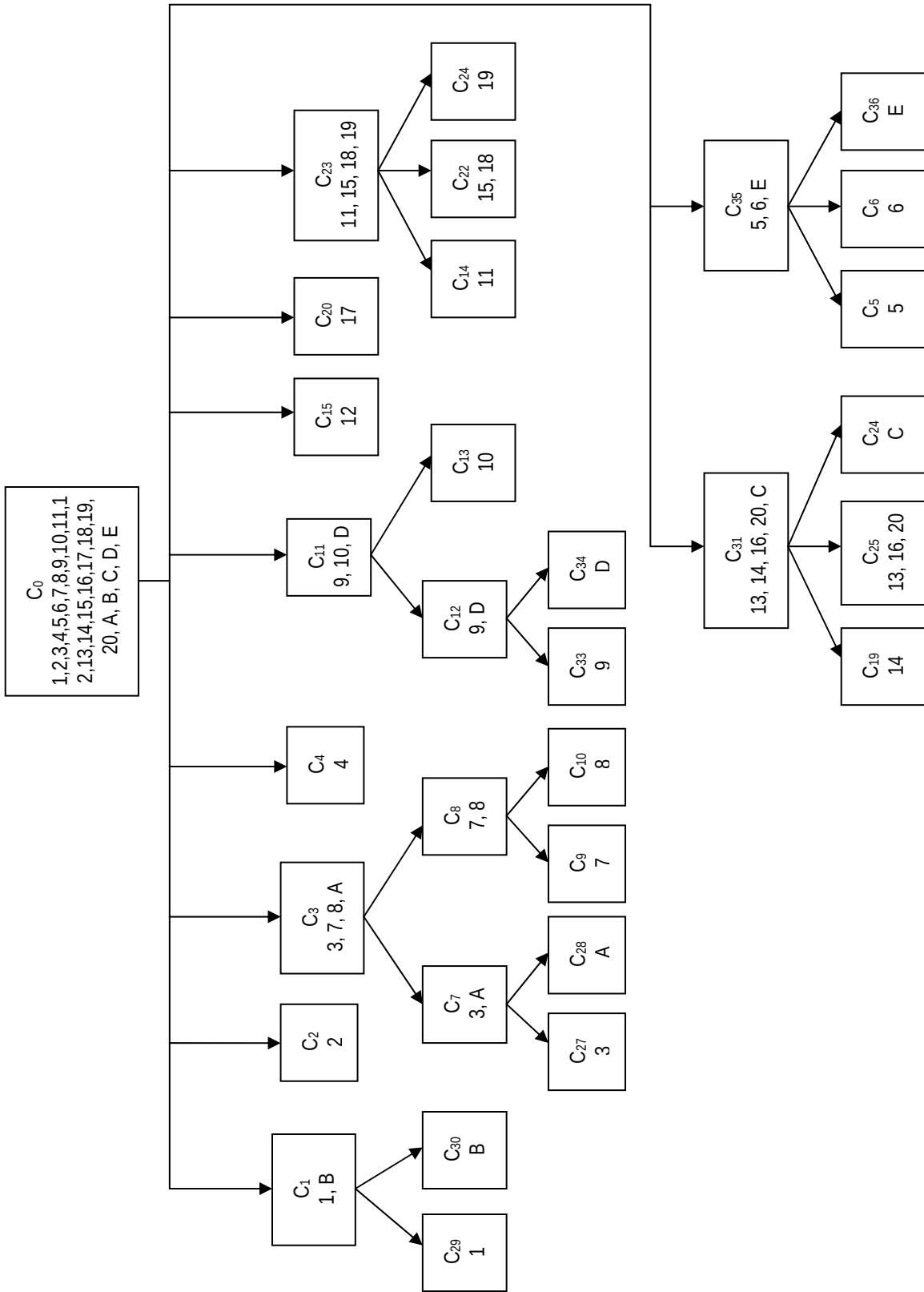
The cluster C_{31} contains five tactical situations that all possess the common attributes of interior lines for REDFOR (but not as pronounced as C_{23}).

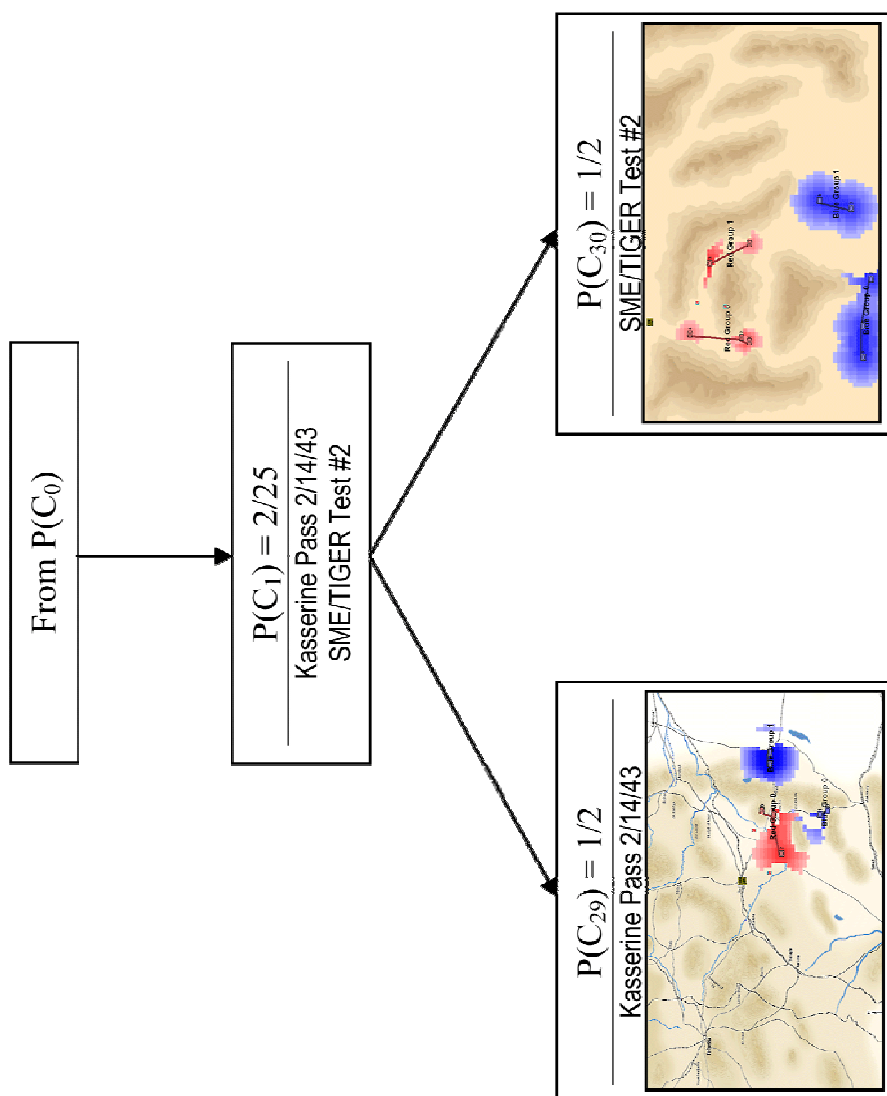
The cluster C_{35} contains three tactical situations that all possess the common attributes of restricted avenues of retreat for REDFOR and neither REDFOR, nor BLUEFOR, have a pronounced advantage of interior lines.

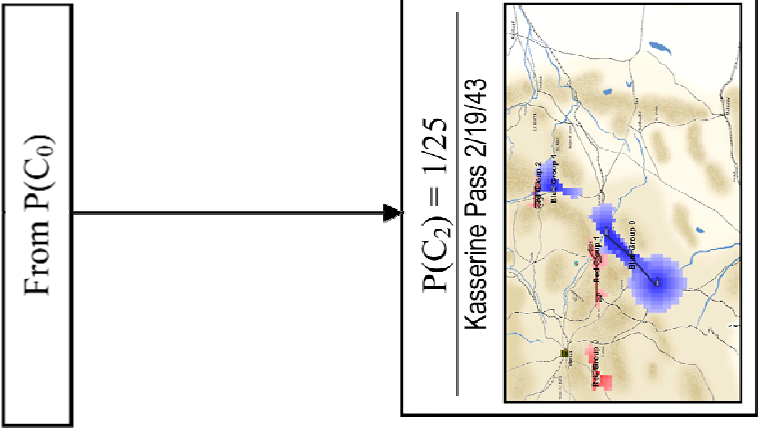
The objects were introduced for classification in the following sequence:

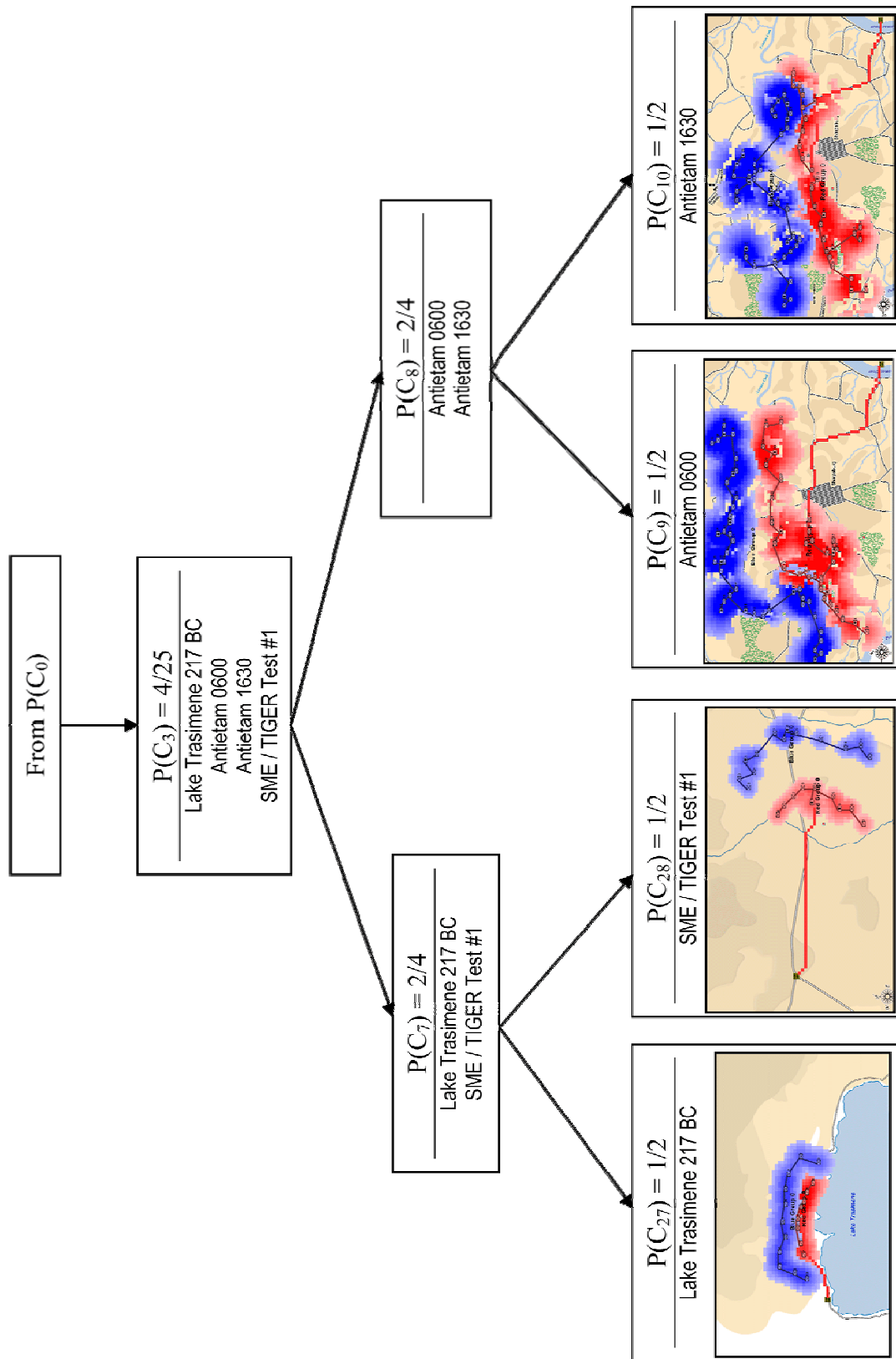
Legend for graph of TIGER classification of 20 historical tactical situations and 5 hypothetical tactical situations.

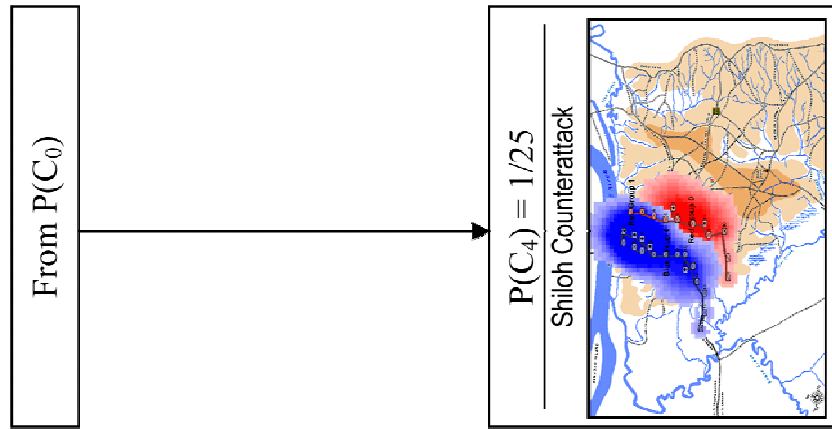
Symbol	Tactical Situation
1	Kasserine Pass February 14,1943
2	KasserinePass February 19, 1943
3	Lake Trasimene, 217 BCE
4	Shiloh Day 2
5	Shiloh Day 1, 0900 hours
6	Shiloh Day 1, 1200 hours
7	Antietam 0600 hours
8	Antietam 1630 hours
9	Fredericksburg, December 10
10	Fredericksburg, December 13
11	Chancellorsville May 1
12	Chancellorsville May 2
13	Gazala
14	Gettysburg, Day 1
15	Gettysburg, Day 2
16	Gettysburg, Day 3
17	Sinai, June 5
18	Waterloo, 1000 hours
19	Waterloo, 1600 hours
20	Waterloo, 1930 hours
A	Hypothetical Situation #1
B	Hypothetical Situation #2
C	Hypothetical Situation #3
D	Hypothetical Situation #4
E	Hypothetical Situation #5

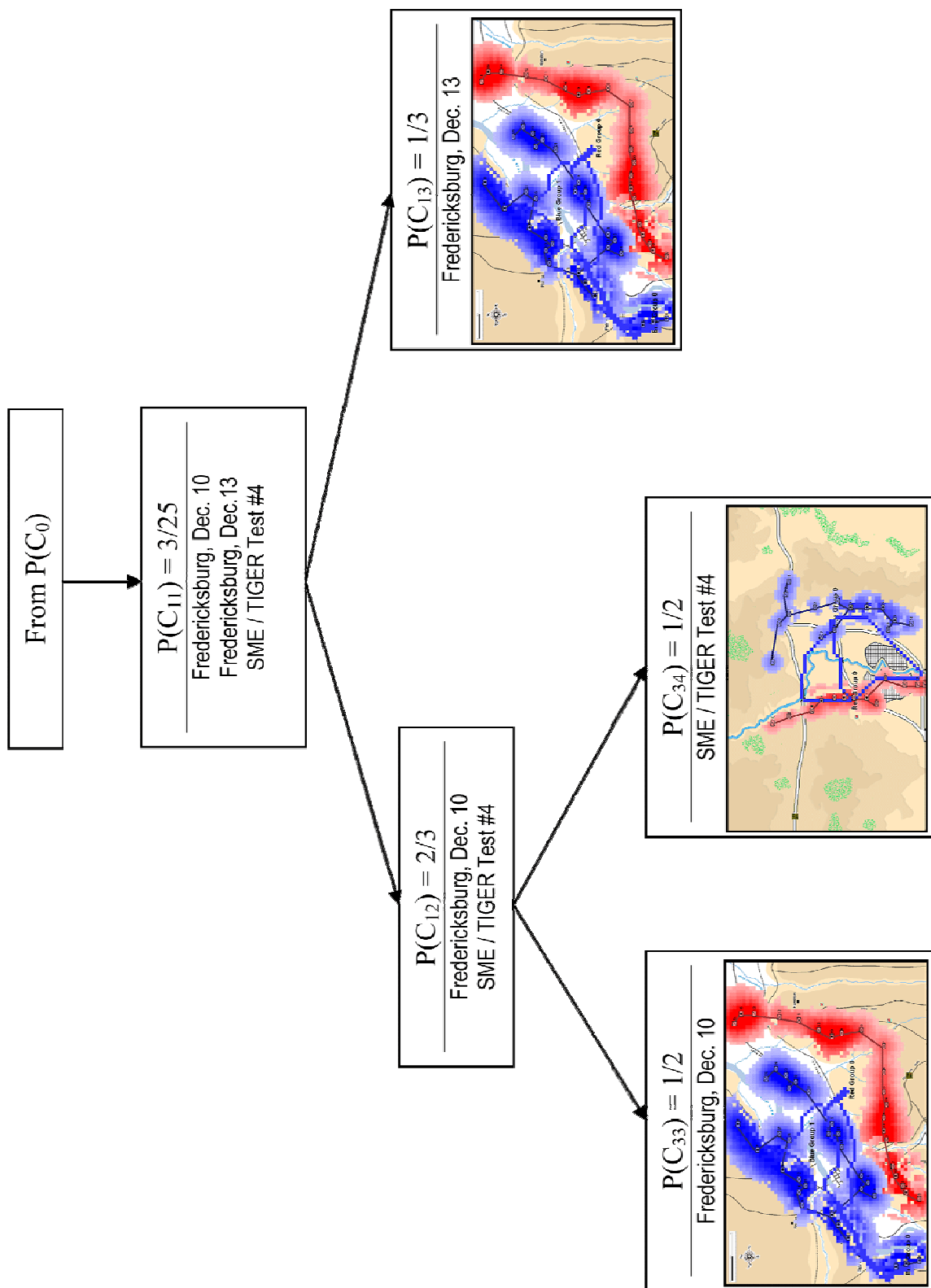


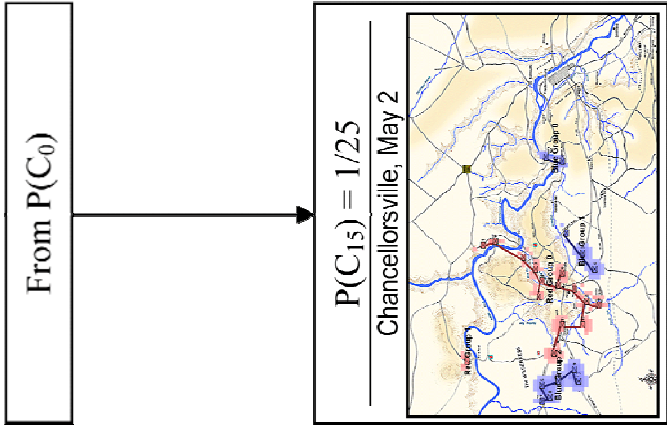


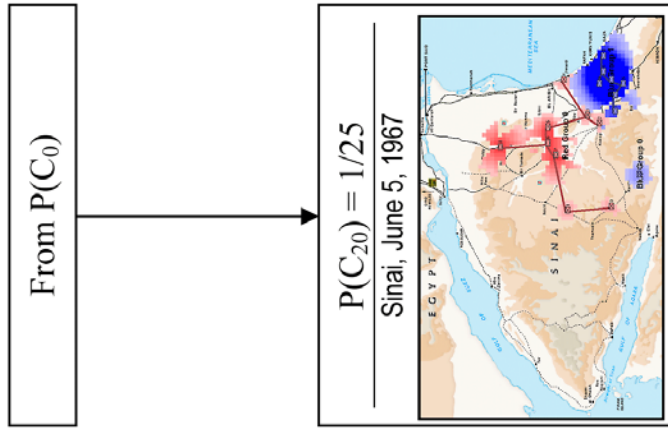


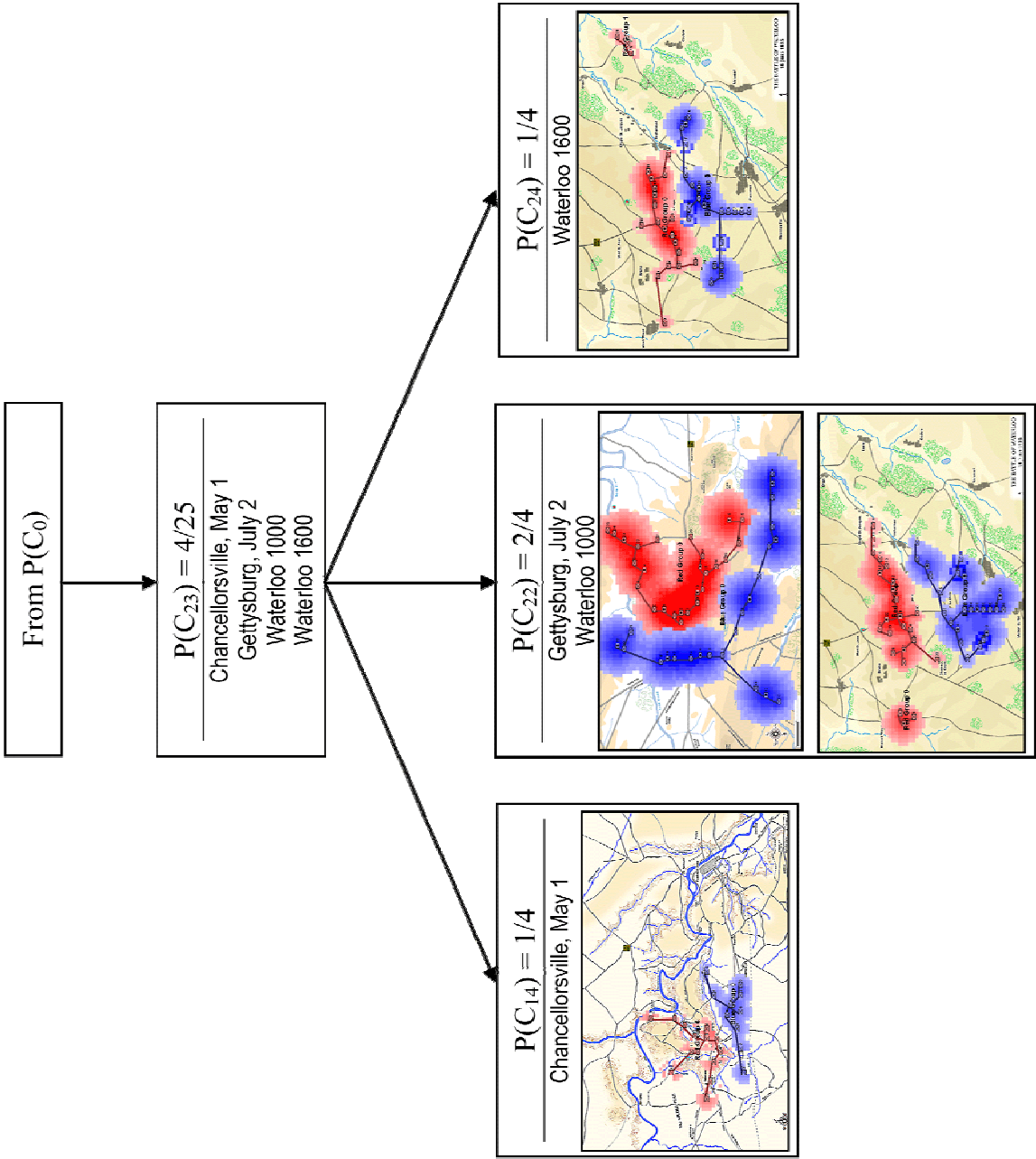


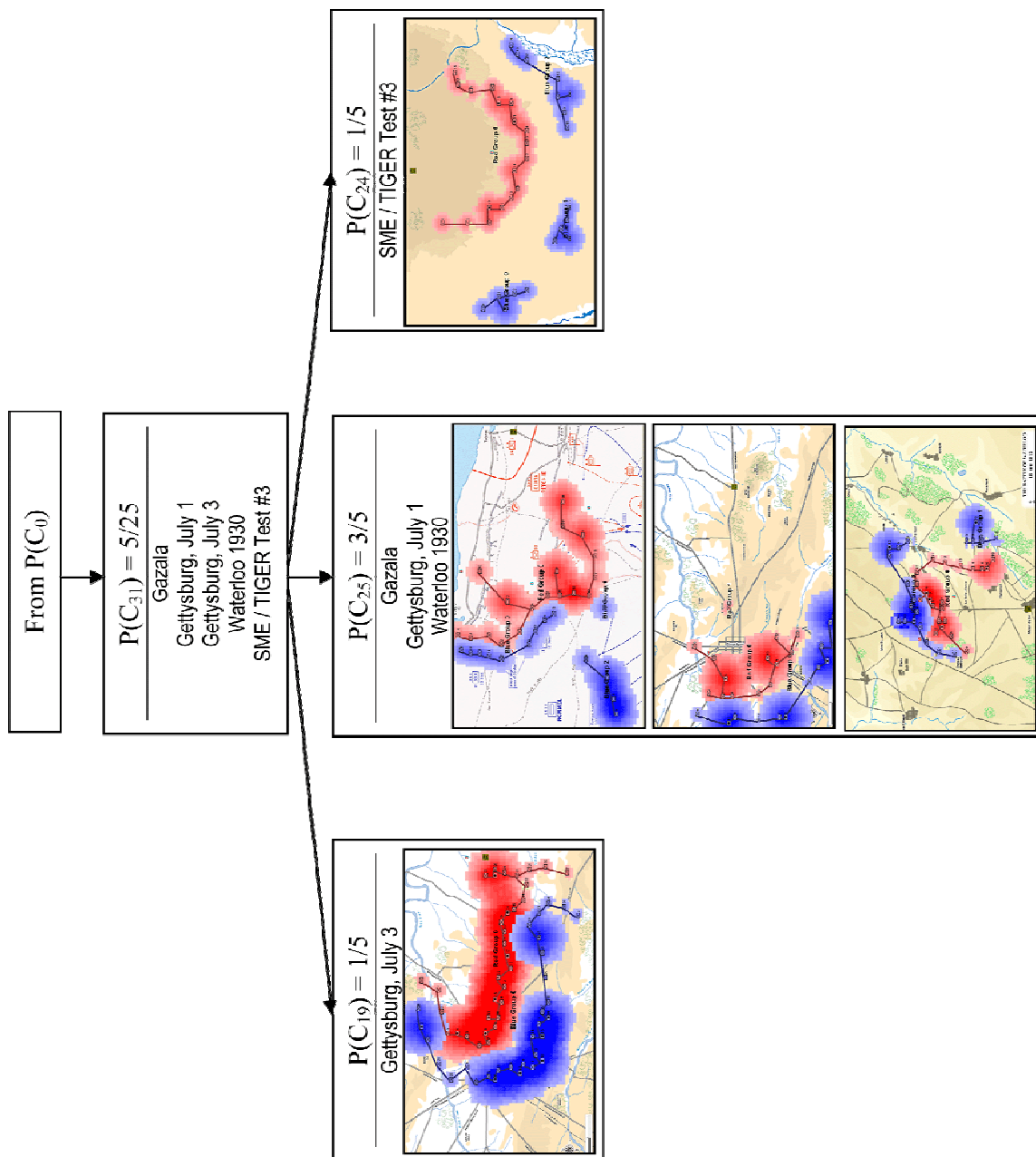


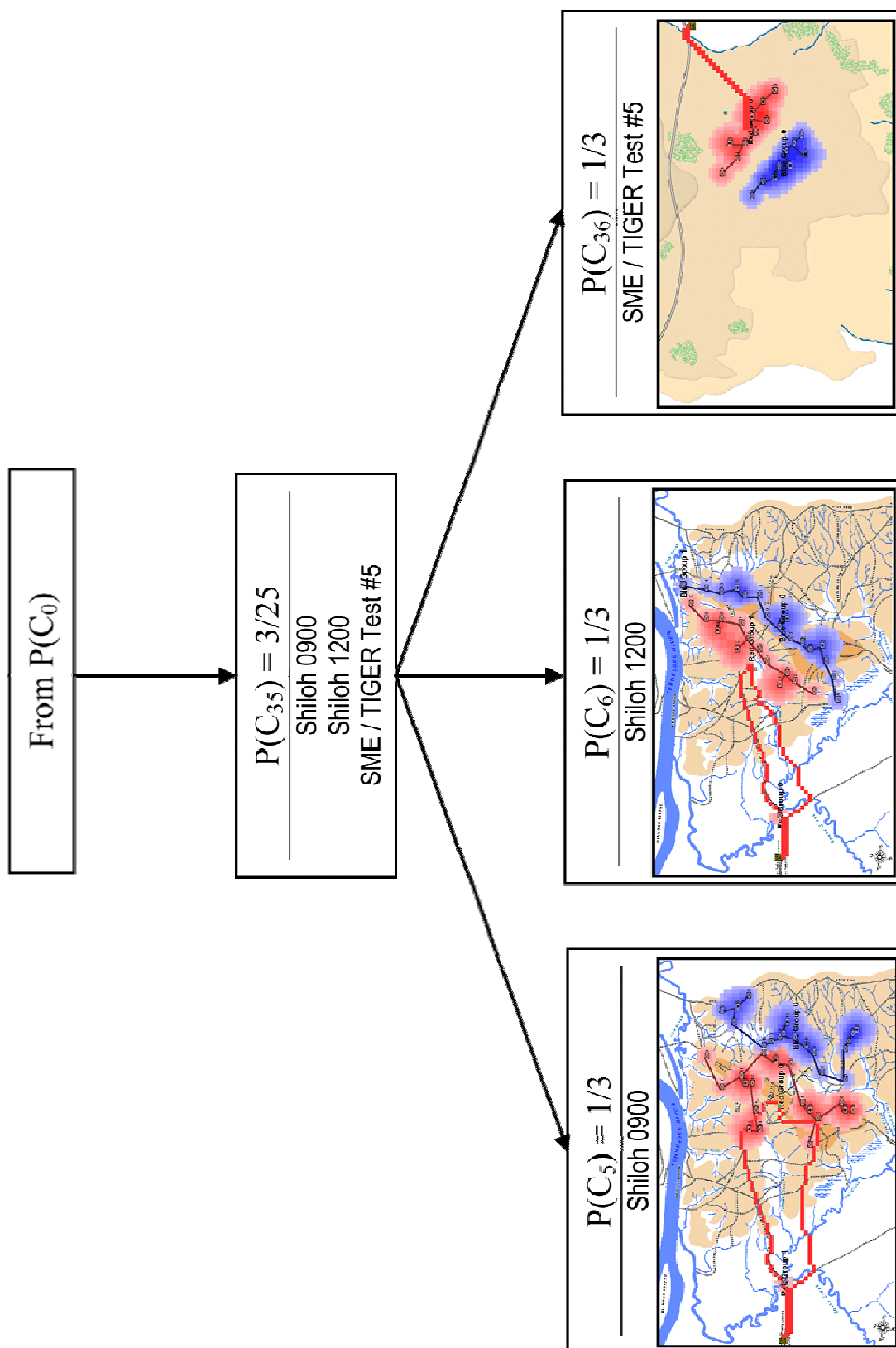












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